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"Quiet, please!" - regulatory protection strategies for the SKA

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Abstract:

For a fruitful return of the large financial investment foreseen in the Square Kilometre Array (SKA) radio telescope, it will need to be able to operate over the ~0.15-25 GHz frequency range in an electromagnetic environment that is increasingly full of man-made interference, driven by commercial pressure. Its key scientific goals require sensitive observations outside the frequency bands allocated by the International Telecommunication Union (ITU) for use by radio astronomy – for example for highly redshifted spectral lines. Besides the development of technical mitigation methods for the suppression of unwanted interference, concerted efforts are being made to explore regulatory protection measures for the SKA. At the ITU, which regulates the worldwide spectrum use, the goal is a Recommendation on an SKA Radio Quiet Zone, for guidance to national spectrum management Administrations on its definition and implementation. At a national level, exploratory discussions on an SKA Radio Quiet Zone and related legislation are ongoing that involve astronomers and Administrations in a number of countries that have proposed hosting the SKA. For these initiatives, the SKA community needs to formulate its desired regulatory protection criteria for the SKA in the near future. The radio astronomical community also needs to explore the implementation of the recommendations made by a Task Force of the OECD Global Science Forum to improve the situation regarding the conflicting spectrum needs of astronomers and other spectrum users, like commercial satellite operators. Furthermore, a stronger involvement from the radio astronomical community is required in regions where radio astronomy interests are not yet strongly represented in the regulatory circuits.

1. Keeping our windows on the Universe clean – the need for spectrum management

Breakthroughs in astronomical research at radio frequencies are foreseen with the future giant instruments ALMA, LOFAR and the SKA, for which the total financial investment will be of the order of 2 billion €/$ - which is still considerably less than the cost of a single major commercial satellite constellation.

The electromagnetic spectrum is a very valuable resource. Like other natural resources, it is precious, finite, and shared by an increasing number of users vying for frequency bands. As a result, the electromagnetic environment in which astronomical observations are made is getting increasingly polluted, driven by commercial interests. In general, non-scientific spectrum use emits radiation at levels that far exceed those emitted by the cosmic sources in which astronomers are interested [1,2].

On the other hand, the sensitivity (and cost) of astronomical instruments is ever increasing, driven by scientific and technological progress, and their fruitful operation requires the ability to perform observations down to increasingly fainter detection levels, and increasingly outside the radio frequency bands allocated for astronomical use. Radio telescopes are very sensitive, and their far sidelobes can pick up interference emitted from positions on the horizon, or from anywhere in the sky, that are far away from the pointing direction of the telescope, and at frequencies well outside the frequency band in which the observations are made.

In principle, two ways are available to enable high-sensitivity observations - one technical (interference mitigation), and the other regulatory (spectrum management) in nature. The saying "Prevention is better than a cure" is also self-evident in this case: the stricter the regulatory limits set on interference levels, the weaker the

unwanted signals to be removed will be – in this sense, regulatory protection measures can be considered as a first-line mitigation technique.

The bottom line will be if by the year 2020 the regulatory and technical interference mitigation measures will be sufficient to deal with the RFI at the SKA sites over the required ~0.15-25 GHz frequency range. Although one cannot accurately predict what the spectrum use will look like around the SKA stations in remote areas 15 years from now, it does seem likely the situation will not improve and that the nature of the RFI will evolve with time.

1.1 Technical means - interference mitigation

Interference mitigation is the term used for the task of identifying and removing unwanted man-made interference signals from the cosmic signals astronomers aim to detect.

The faint cosmic emissions we want to observe are usually rather noise-like in nature, compared to man-made interference signals. This allows the development of various methods and algorithms to separate the two in the time-frequency-polarisation domain. The ultimate aim is to reject unwanted interference, without degrading the quality of the astronomical data. Considerable efforts are made to develop new methods and spectacular results have been obtained, as is evident from these Proceedings.

1.2 Regulatory means – spectrum management

Spectrum management (or frequency management) is the term used for the task of accommodating all competing services and systems within the finite usable range of the (radio) spectrum, which includes setting limits on unwanted emissions (interference) emitted by other spectrum users into frequency bands allocated for astronomical research [3,4].

Astronomical spectrum management requires different kinds of interactions with quite different organisations, range from town- and county councils, through national Administrations and regional coordinating commissions, to global forums like the ITU and the OECD. An example of a “local” spectrum management task is coordinating the installation of the increasingly ubiquitous GSM emitters near a radio observatory, of “national” concern is the definition and implementation of Radio Quiet Zones, a “regional” problem can involve coordinating multi-national use of frequency bands, and “global” issues usually concern the worldwide Radio Astronomy Service and involve amending the ITU Radio Regulations and Recommendations.

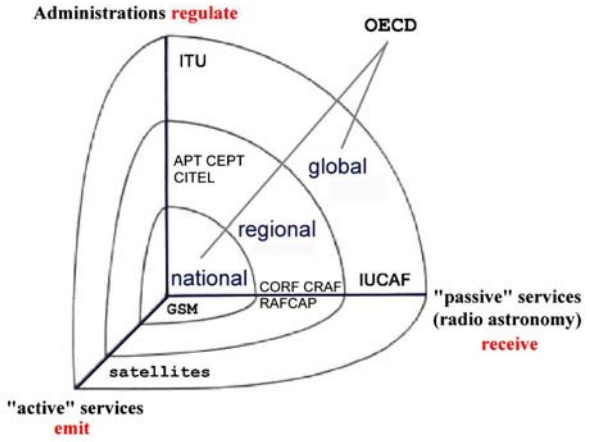

Fig. 1 In practice, spectrum management for the protection of astronomy involves activities on quite different levels – the “problem space” of spectrum management is sketched in the Figure to the left, which shows the different players involved at local, regional and worldwide scales. The role of administrating agencies like national Administrations and the ITU is to find equitable solutions for the spectrum use needs of the so-called “active” radio services (like broadcasting, both terrestrial and satellite), which emit radiation, and the “passive” services (like astronomy and Earth Exploration by Satellite), which receive radiation only. The role that the OECD, a discussion forum for senior science policy officials, can play outside the established regulatory structures needs to be explored further.

2. Spectrum management in practice – Administrations and astronomers

2.1 At a national level: Administrations

The spectrum management process is mainly the responsibility of national spectrum management Administrations, which are mandated to use all possible means to facilitate and regulate radiocommunication in a specific country, in accordance with the ITU Radio Regulations. This includes the enforcement of regulations

and the protection of the interests of all users of radio frequencies, both “active” (i.e., emitting) and “passive” (receiving only – e.g., radio astronomy).

Good contacts with Administrations are crucial, as they regulate, e.g., the implementation of Radio Quiet Zones or exclusion- and coordination zones around radio observatories, in which limitations are set on emissions harmful to radio astronomy observations (see also Section 3.2).

2.2 At a global level: the International Telecommunication Union

The body that is responsible for co-ordinating spectrum management at the global level is the International Telecommunication Union, ITU (see also Gergely, these Proceedings). The global framework for spectrum management is provided by the Radio Regulations of the ITU [5], which have international treaty status and thus are binding for all members of the ITU. They provide rules to national Administrations that allow them to regulate equitable access to the radio spectrum for all entities requiring frequency allocations. The Radio Regulations contain the international Frequency Allocation Table.

In order to modify the Radio Regulations, the ITU organises a World Radiocommunication Conference (WRC) once every three years on average, which is attended by over 2000 representatives of 180+ national Administrations and other accredited organisations, such as IUCAF, and which lasts for a month. At each WRC the agenda items are fixed for the next WRC – these generally concern proposals for the allocation of specific frequency bands for specific purposes, which may cause interference or other conflicts with other users of the spectrum. Over the next three years, these potential conflicts are then studied in the various Working Parties and Task Groups of the ITU, whose results serve in the decision making process of the next WRC.

At present, astronomers representing IUCAF attend meetings of ITU Working Parties 4A (fixed satellite service), 7D (radio astronomy) and 8D (mobile satellite service) and Task Groups 1/8 (ultra-wide band devices) and 1/9 (unwanted emissions from satellites), as required, besides numerous national and regional preparatory meetings.

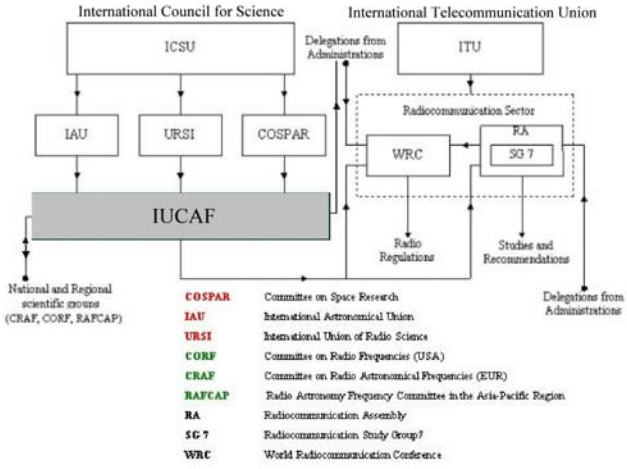

Fig. 2 The complex structure centred on the ITU is sketched in the Figure to the left. In the left half of the picture, under ICSU, one finds the three sponsoring scientific organisations of IUCAF, COSPAR (space science), the IAU (astronomy) and URSI (radio science), and IUCAF – note the links between IUCAF and the regional organisations of astronomers involved in spectrum management (CRAF, CORF and RAFCAP) and the national delegations that attend ITU meetings. The right half indicates the various ITU forums – note the WRC, where once every 3 years the Radio Regulations are amended, and the various Study Groups (including SG7 for Science Services, which includes Working Party 7D on radio astronomy) where studies are performed related to WRC agenda items on proposed frequency allocations and to various Questions (like on Radio Quiet Zones) and updates of ITU Recommendations.

2.3 At a global level: the OECD Global Science Forum

Besides the well-established circuit of national Administrations, regional organizations and the ITU, another route that merits to be explored for solving spectrum management issues involving astronomy is through the Organisation for Economic Co-operation and Development (OECD). The Global Science Forum of the OECD is a venue for meetings of senior science policy officials of OECD member countries, with as goal to identify and maximise opportunities for international co-operation in basic scientific research.

It organised a Task Force on Radio Astronomy and the Radio Spectrum to examine the spectrum use requirements of the astronomy and satellite telecommunications communities, to identify the nature of the potential inconsistencies in their spectrum requirements, to look ahead at the trends that may tend to ameliorate

or aggravate the problem, and to recommend practical steps to improve the situation. The recommendations of the Task Force include [6]:
- The establishment of a forum for technical experts from both communities for information exchange and collaboration on the planning, designing and manufacturing of new satellite systems and radio telescopes, before the designs become final;
- The consideration of mechanisms to promote co-operation and reduce potential conflict between the interests of both communities, especially at the small number of future high-sensitivity observatories like ALMA and the SKA, which include the establishment of "Controlled Emission Zones" (based on agreed technical and economic feasibility);
- Consultations, between satellite operators and radio astronomers regarding ways to share real-time operational information that would permit the scientists to reduce interference.

2.4 Coordinating astronomers worldwide: the role of IUCAF

IUCAF (the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science) is the international organisation representing the unfettered views of passive scientific users of the radio-frequency spectrum at the ITU (International Telecommunication Union). It operates under the auspices of ICSU, the International Council for Science. IUCAF is sponsored by the International Astronomical Union (IAU), the International Union of Radio Science (URSI) and the Committee on Space Research (COSPAR). IUCAF is an accredited Sector Member of the ITU, and IUCAF members can also attend ITU meetings as part of national delegations, if these allow this. For more on the past and present of IUCAF, see, e.g., [7] and [3] and its website `www.iucaf.org)`

IUCAF has 13 members, who also play active roles in representing the needs of astronomers at their national Administration and within the regional regulatory coordination bodies, as members of the regional bodies of astronomers involved in regulatory protection of astronomy (CORF in the US, CRAF in Europe, and RAFCAP in the Asia-Pacific region). They also maintain close ties for concerted actions with other "passive" spectrum users, such as in the Earth Exploration Satellite Service (with NASA, ESA, CNES, etc., and through the Space Frequency Coordination Group).

IUCAF is organising an expansion in its regional coverage, through the establishment of a group of Correspondents, from those regions (Africa, South America) where radio astronomy interests are not yet strongly represented in the regulatory circuits – this is of importance for, e.g., obtaining the support of regional coordinating bodies at the WRCs where the ITU Radio Regulations are revised.

IUCAF astronomers are also involved actively in various aspects the SKA project: scientific, technical, site evaluation (including measurements of the RFI environment) and regulatory.

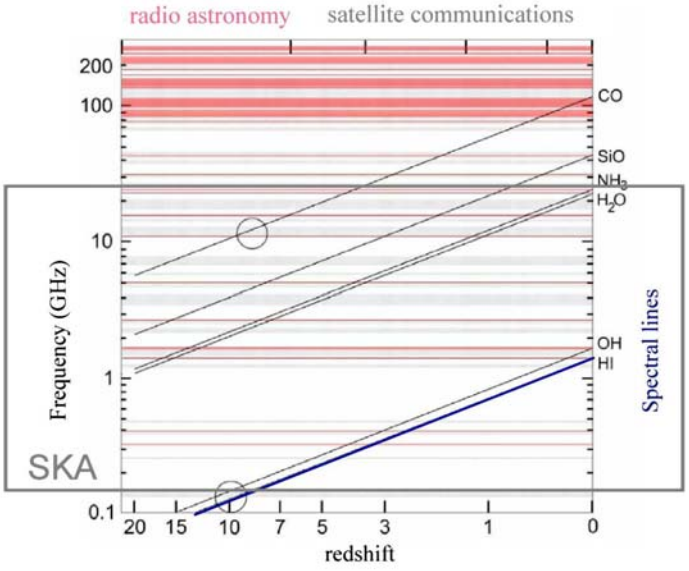

Fig. 3 The allocation of frequency bands in the ITU Radio Regulations to various Services using the radio spectrum is shown here for the 0.1 – 300 GHz range – the grey rectangle indicates the ~0.15 – 25 GHz range of the SKA. The horizontal pink bands show the bands allocated to radio astronomy (amounting to only a few percent of the SKA range), all other frequencies are allocated to applications that emit radio signals which are in general (much) stronger than the signals to be detected by the SKA. Frequency bands allocated to satellite services are indicated in grey, while the white areas are used by other active spectrum users. A number of important spectral lines have been indicated on the right, together with the shift of the frequencies at which they are observed as function of redshift (source: OECD)

3. Seeking regulatory protection measures for the SKA

The key scientific goals of the SKA will require sensitive observations of objects at cosmological distances, whose spectral lines have been red-shifted far outside the frequency bands currently allocated to the Radio Astronomy Service by the ITU (Fig. 3), in which protection can be claimed from harmful interference by active spectrum applications. For the successful operation of the SKA regulatory protection measures will need to be sought over its entire frequency range of ~0.15-25 GHz.

In the ~0.15-25 GHz range only about 2% is allocated to the Radio Astronomy Service – for example, the 1400-1427 MHz band allocated for observations of the 21cm HI line covers redshifts out to 4300 km/s only. All other frequencies are used by active services, terrestrial, aeronautical and space-borne, whose transmissions will be up to many orders of magnitudes stronger than the cosmic signals the SKA is built to detect.

Requesting regulatory protection of SKA operations outside allocated radio astronomy bands could in principle be covered under Recommendation ITU-R RA.314 on "Preferred frequency bands for radioastronomical measurements", which recommends that "administrations be asked to provide assistance in the coordination of experimental observations of spectral lines in bands not allocated to radio astronomy".

Of particular concern to the operation of the SKA are satellite emissions, since the national Administrations that implement Radio Quiet Zones cannot put regulatory limits on emissions from satellites outside the frequency bands allocated to radio astronomy. Efforts are being made in the ITU since many years to limit the unwanted emissions of satellites, specifically concerning the tightening of the generic limits set in Appendix 3 to the Radio Regulations for specific satellite/astronomy band-pairs. However, limiting satellite emissions in ways that will be of benefit to the operation of the SKA in its effective frequency range will depend mainly on consultation, coordination and negotiation between the radio astronomy community and satellite designers and operators (see also Sect. 2.3).

3.1 Through the International Telecommunication Union: Recommendations

3.1.1 Recommendation ITU-R RA.769 on unwanted emission threshold levels and the SKA

Inside the bands allocated to radio astronomy the levels on interference detrimental to astronomical observations are given in Recommendation ITU-R RA.769 on "Protection criteria used for radio astronomical measurements" (a.k.a. "Rec 769") – see Gergely, these Proceedings, for further details.

Often, the Rec 769 levels on detrimental interference are considered "extreme" by other (active) spectrum users, who rather regard them as an opening bid from the radio astronomy side in negotiations on "practicable" interference levels. In fact, the Rec 769 levels are those above which radio astronomical data are degraded if no appropriate mitigation techniques can be applied. When the level of interference rises 10 dB or more above those given in this Recommendation, then increased observing time will no longer be effective in ensuring that valid scientific data are provided.

Although the Rec 769 "hard limit" protection levels are *de facto* included in Footnotes on protection criteria to certain radio astronomy bands in the Radio Regulations, in principle it is a Recommendation only, which national Administrations can ignore if it so pleases them (e.g., for commercial reasons).

The strength of the "workhorse" Rec 769 lies in the fact that is as generic as possible, it is based on simple physical principles and it does not require detailed telescope- or site-specific input parameters. It assumes, e.g., that all interference enters through isotropic far sidelobes at the 0 dBi level and it therefore does not depend on the telescope diameter.

Recommendation 769 gives interference threshold levels for continuum (broadband) and line (narrow-band) observations for single-dish and VLBI observations in the bands allocated to radio astronomy (Fig. 4). Using the principles and input parameters of Rec 769, these threshold levels can easily be calculated over the entire SKA frequency range.

Concerning the diminished susceptibility of an interferometer, like the SKA, to interference, compared to a single-dish telescope, it is noted in Rec 769 that "the interferometer has a degree of immunity to interference which, under reasonable assumptions increases with the array size expressed in wavelengths." This has been worked out further in the ITU Handbook on Radio Astronomy [1], which shows an illustration like Fig. 4, in which the detrimental interference threshold levels are compared for single-dish telescopes, existing interferometers with increasingly long baselines, and VLBI observations, in which the interference signals recorded at the various sites will be completely uncorrelated.

It should be noted that no RFI mitigation methods, like those described in these Proceedings, were considered in deriving the interference threshold levels given in Rec 769.

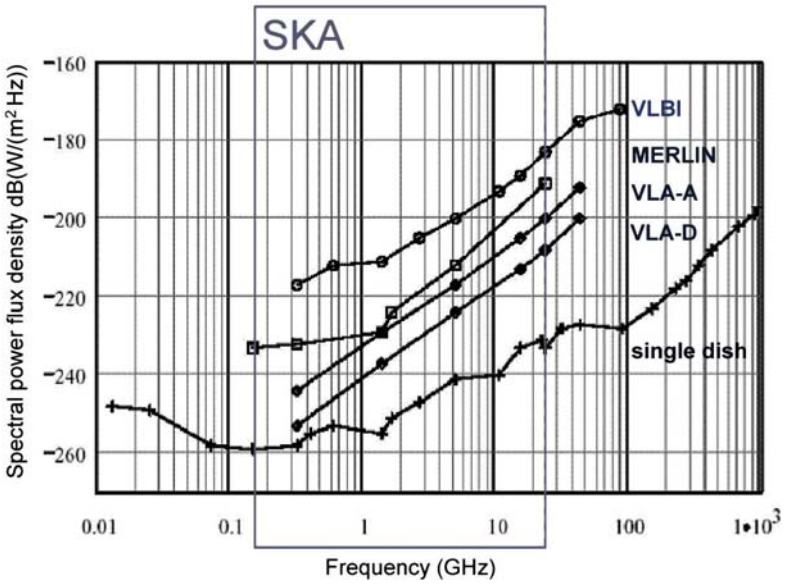

Fig. 4 Detrimental threshold levels of interference for continuum observations with several types of radio telescope systems, based on Recommendation ITU-R RA.769. Crosses are for single-dish observations. Diamonds are for the VLA, lower curve for its D configuration (longest antenna spacing 1 km) and upper curve for it's a configuration (longest antenna spacing 36 km), squares are for the MERLIN array (longest antenna spacing 218 km), and open circles for VLBI. The grey rectangle indicates the frequency range of the SKA, ~0.51-25 GHz.

3.1.2 Towards an ITU-R Recommendation on an SKA Radio Quiet Zone

At present, there is no ITU-R Recommendation on Radio Quiet Zones, to give guidance to national Administrations on the principles and requirements of these Zones, of which a number have already been created throughout the world (see Tzioumis, these Proceedings).

It should be noted that these Zones are "radio quiet" (with regulatory restrictions on RFI levels) rather than "radio silent" (free of RFI) – even in the Shielded Zone of the Moon, on the far side of our natural satellite, which will shield emissions from artificial satellites orbiting the Earth, there will be RFI.

For the SKA Radio Quiet Zone we will need to define the desired regulatory protection criteria for its successful scientific operation, including limits to be set on detrimental interference from active spectrum use in the country/countries hosting SKA stations. It will need to be examined further if the compact core, inner arms and outlying stations of the SKA will need different protection limits (e.g., those for single dish, interferometer and VLBI, respectively - see Sect. 3.1.1), or if a "one limit fits all" criterion can be applied.

In any case, these protection criteria will need to be based on the principles of Rec 769, which has been in the ITU Radio Regulations since long, known to all Administrations, based on straightforward physical principles and relatively simple to use.

At the ITU World Radiocommunication Conference (WRC) in 2003, an effort was made by astronomers to get an Agenda Item on SKA and ALMA Radio Quiet Zones scheduled for the next WRC, in 2007. Despite support from the European and Asia-Pacific blocs, this did not work out. Given the ITU procedures, it was then decided to work on the introduction of an ITU-R Question on Radio Quiet Zones that would meet with the approval of all national Administrations, which would allow technical studies to be carried out towards a ITU-R Recommendation on Radio Quiet Zones, resulting eventually in the reconsideration of a WRC-2010 Agenda Item on this issue, if required.

The required Draft New Question on Radio Quiet Zones was adopted in March 2004 by Working Party 7D (radio astronomy) of the ITU-R, and the SKA community will need to provide technical input for it and its ensuing Recommendation.

3.2 Through national spectrum management Administrations: the SKA Radio Quiet Zone

As mentioned above, national Administrations have a large leeway in defining regulatory ways and means to protect the site of the SKA, which includes the creation of an SKA Radio Quit Zone with limits on RFI levels in the area surrounding SKA stations.

The SKA community will need to formulate its desired requirements for regulatory protection in the SKA Radio Quiet Zone. This Zone will be unlike any other established before (Tzioumis, these Proceedings), given the large number of stations and the large baselines of the instrument. Particular thought needs to be given to restrictions on mobile terrestrial and airborne transmitters, as these are more complicated to regulate than fixed terrestrial transmitters.

For a number of proposed SKA sites, the creation of a Radio Quiet Zone will have unprecedented international implications [8], since the outlying SKA stations will not be on the territory of the country hosting the inner parts of the array. This will require close contacts and collaboration with several Administrations, sometimes of countries that have no experience yet with radio astronomy and its particular regulatory requirements. Given the potential legal scope of establishing this Zone, it will also require specific national legislation.

Exploratory discussions on regulatory protection issues have already started with the spectrum management Administrations of some countries that have proposed to host the SKA. These Administrations will want to hear about our desired protection criteria as soon as possible, in order to study how an SKA Radio Quiet Zone could be implemented.

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