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13AUG15

Square Kilometre Array Organisation (SKAO)

Response to Ofcom Call for Input – Strategic review of satellite & space science spectrum

The Square Kilometre Array Organisation (SKAO) has considered the Ofcom 'Call for Input' (CFI) to its review of the satellite & science services sectors and appreciates the opportunity to take part in the consultation and provide information.

The SKAO is the entity leading the Square Kilometre Array (SKA) radio telescope project; its global headquarters is in the United Kingdom at the Jodrell Bank Observatory. The telescope will operate from two sites in the southern hemisphere and is one of the most visionary and ambitious science projects of the 21st century, the first phase alone costing 650MEuro. The SKA radio telescope will be the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. When fully deployed it will incorporate a receiving surface of a million square metres, fifty times larger than the biggest receiving surface now in existence. As a major new scientific facility, the SKA will have an enormous impact extending well beyond its immediate science environment. The SKA has been recognised as one of the European Strategy Forum on Research Infrastructures (ESFRI) 'Landmark' projects in its 2016 Roadmap. For more information please visit: www.skatelescope.org.

Overview of our input
Whilst section 2.4 of the CFI shows Ofcom's appreciation of the international context of spectrum use in the science services, it is clear that the output derived from the consultation will focus on the current and future use of 'UK spectrum'. As a multi-national project based operationally in the southern hemisphere, the SKAO's responses to some of the questions may not have the same impact for the CFI as those from UK observatories. SKAO has somewhat different spectrum access rights in its hosting countries: designated Radio Quiet Zones (RQZs) of 70 MHz – 25.25 GHz in Australia and 100 MHz to 25.5 GHz in South Africa. Consequently, in response to some of the questions an SKAO perspective may not be provided; Ofcom is referred to responses made separately by ground based observatories of the UK RAS.

Question 1: Do you have any comments on our approach to this review?

We should not lose sight of the fact that although this CFI is 'space focussed', ground-based radio astronomy is significantly influenced by potential sharing, co-existence and interference issues with terrestrial and airborne telecommunications systems and this will also drive some elements of decision making and operational planning.

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The nature of the document draws what appears to be quite a distinct line between the satellite sector and the science services sector. Particularly for regulatory matters of sharing & co-existence we believe that the two sectors cannot be simply segregated. Article 29 of the Radio Regulations makes quite clear that it has been appreciated for some time that a significant threat to the operation of ground-based radio astronomy observatories comes from airborne and satellite systems. Conversely, the existence of RAS stations does influence the design and development of satellite systems. In the future, the interference received at radio astronomy sites is likely to be proportionately greater from satellite systems and airborne platforms than at present. We feel that some sort of forward looking joint regulatory and spectrum engineering concepts might have been addressed - see also later comments on mitigation & regulatory action.

Our second comment concerns the value chain analysis approach used. Value Chain Analysis was originally a process oriented business tool for identifying which activities necessary to generate a product or output are best undertaken within a given system and which are best "out sourced". However, governments and development agencies are increasingly using value chain analysis as a key element in their development strategies. Many differing value chains can be constructed depending on the perception of what 'value' actually means from the particular standpoint of the approach that is chosen to describe the process. We feel that the value chain approach as specifically offered in the document may suit assessment of individual commercial organisations in the satellite sector reasonably well, but that the way in which it has been applied does not suit the organizational and operational environment of the fundamental research that is undertaken in UK ground-based astronomy and probably other science services.

Question 3: Do you have any comments on our broad overview of the space science sector? In particular, do you have comments on the completeness of the list of applications, their definitions and their use of the relevant radiocommunications service(s)?

In section 3.10 under passive applications, the international VLBI service (IVS) for geodesy and astrometry - http://ivscc.gsfc.nasa.gov/ may well need to be identified, even though it may be intended to be included implicitly.

It may also be useful to recognise that hybrid systems can occur: e.g. the use of ground-based radio astronomy observatories together with radio telescopes on satellites to generate very long baseline interferometry systems.

Question 14: Do you have any comments on our representation of the value chain for the space science sector? How do you think industry revenues are broken down between players at different positions in the chain?

Considering the value chain presented specifically in relation to ground-based radio astronomy; i.e. that launch providers and satellite operators are not in the chain; and, that the earth station/teleport operators are the observatories themselves, then most ground-based radio astronomy groups conducting fundamental academic

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research are usually involved in all parts of the chain in some way. SKAO is one such: devising observations to answer fundamental scientific questions; specifying and producing equipment & software; overseeing the installation & commissioning of the same in the observatory; control of the data collection and analysis software; and ultimately, also being users at the end of the chain participating in further analysis. In the context of the Ofcom CFI exercise this clearly produces an issue relating to the validity of the chain for ground-based astronomy, even though it is stated in Section 5.4 that Ofcom appreciates that "individual companies may play more than one role in the chain".

Question 15: What is the extent of your organisations' role(s) in the value chain? Which space science applications (as summarised in Table 2 in section 3) does your organisation:

- use;
- provide; or
- help to deliver?

As stated in Q14, for the SKA project, the SKAO will drive all elements of the value chain as presented. The SKAO provides a strong central project office that holds the project management and system design authority. The design work on major subsystems has been awarded by the SKAO to eleven Work Package Consortia (WPC). The WPC are groups of organisations drawn primarily from the member countries, and the scope and delivery of the work required through to the end of the SKA first phase pre-construction is governed by formal agreements between the WPCs and the SKAO. It is expected that in the construction phase work will be delivered by a combination of in-kind contributions and direct industry contracts.

Question 16: For each of the space science applications you use, provide or help deliver (as identified in Question 15), and taking into account your role in the value chain, where applicable please provide:

- the specific spectrum frequencies used, distinguishing between the frequencies used for the science application, the frequencies use for downlinking data and, for TT&C;
- whether the application is limited to use of specific frequencies and why (e.g. due to fundamental characteristics of the phenomena being measured and/or availability of technology designed for that frequency);
- whether the applications use continuous or intermittent measurements;
- the typical resolution and associated measurement bandwidths, including an indication of any implication for spectrum requirements;
- the geography this use extends over (e.g. land or sea, and regional or global);
- the location of the gateway station(s) for TT&C and downlinking data;
- the estimated number of users.

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Whether at UK radio astronomy observatories or the SKA, the diverse nature of the research being conducted and hence many different types of observations that are undertaken, often at multiple frequencies, will produce a very dense amount of information in response to the items in the list presented above. We emphasise that many of the frequencies used are dictated by fundamental natural characteristics and processes. This is reflected in the agreed ITU-R allocations to science services. For the SKA, a fundamental part of its operational requirements are the Radio Quiet Zones (RQZs) defined earlier; they allow significantly different and more access to spectrum in its host countries in the southern hemisphere than Observatories have in the UK. Consequently the most pertinent responses to this question will be from the UK Observatories.

Question 17: For each of the space science applications you provide, please could you indicate how UK consumers and citizens benefit from their use? Where possible please also provide an indication of the scale of the benefits (either qualitatively or quantitatively).

The benefits of any fundamental scientific research tend to be gradually felt in many different areas of human experience over the very long-term and are therefore hard to quantify in purely monetary terms. For consideration of the value of radio astronomy in broader terms please see Report ITU-R RS.2178: *"The essential role and global importance of radio spectrum use for Earth observations and for related applications"*

The SKA is primarily an engineering project for the next ten years before it becomes a fully functioning, active observatory and continues on into the second half of the 21st century. The activities of the assembled technicians, scientists, and engineers will be an engine for invention and innovation, leading to benefits to society that will precede the astronomical discoveries eventually made from observations using the telescope itself.

A major facet of the SKA is that it will help drive technology development particularly in information and communication services. The computing requirements of the SKA will exceed those of the fastest High Performance Computing (HPC) systems presently available by a factor of 10 and so the SKA has the potential to help drive general innovation across the HPC, big data processing and cloud computing sectors because of the technological challenges that the project will tackle. As an iconic project, the SKA will potentially:

- affect international standards for ICT engineering and construction, hardware and software
- improve the energy efficiency of ICT from the individual component level through to data centre design
- affect or spur the development of global sensor networks useful for commerce and government
- lead to environmental applications where natural events are detected and analysed in real time
- influence the development of smart, world-wide communications
- provide relevant models, protocols, and microelectronics to handle the enormous future traffic of internet data
- drive innovations in algorithms and software that will be useful in many diverse fields

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Nations that participate in the SKA would reap considerable socio-economic benefits by being at the forefront of these developments. As a key player, the UK should benefit accordingly. Specifically it is anticipated that the successful drive to innovation described above will undoubtedly offer benefits, such as:

- increased productivity in research
- the provision of additional resources, support and enhanced career opportunities
- opportunities to apply research results to industrial problems
- enhanced university prestige
- enhanced quality and recognition of patents for firms with scientific affiliations

More widely, as a major new scientific facility driven by researchers motivated by scientific goals, and needing collaboration beyond that achievable by a single country, the SKA will have an impact extending well beyond its immediate science & technology environment. From the earliest ideas throughout the development of the SKA concept, close attention has been paid to the potential non-science benefits of the SKA. In addition to the direct ICT and telecommunications impacts listed above we believe that there will be other areas of benefit such as:

- Green Energy
- Global Science-Industry-Government Linkages
- Human Capital

Green Energy: The commitment to move towards an increasing use of green energy will also present a major ICT challenge. Today, there are no major computers or networks that run entirely from renewable energy. As the SKA explores avenues to increase its use of renewable energy sources, a parallel and significant research and innovation effort would be needed to enable the SKA to fulfil its potential to become the most sophisticated ICT network running on locally-generated, renewable energy. If this can be achieved, SKA could be a test-bed and pathfinder for other networks and organisations and could, in turn, open up markets for remote and local power generation. Such innovative design engineering would be only partly specific to the SKA: much of it would also be useful to other geographically distributed sensor networks and could be a model for the future.

Global Science-Industry-Government Linkages: SKA will be the first truly global science infrastructure. The mega-scale of the project introduces both challenges and opportunities for dealing with all aspects of such a development: research support, science-industry-government 'mega data' protocols, as well as systems integration. Uniquely, the global science-driven nature of the SKA will address these challenges in an environment of participation and collaboration across international borders whilst respecting cultural differences, acknowledging relative regional capacity and managing diversity amongst all project partners and stakeholders. International collaboration and industrial engagement will be the focus.

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International collaboration: The SKA will involve participation from many nations. It is perhaps uniquely international in the field of astronomy projects and research infrastructures more broadly. The importance of respecting cultural differences whilst maintaining diversity amongst all project partners was recognised early, and is an integral part of the development of the necessary arrangements for formal legal frameworks for the project. These include legal governance frameworks, tax systems, procurement processes, labour laws and in forging agreements how the IP generated will be fairly attributed. In addition, the funding model established for the future SKA Organisation will ideally have developed algorithms sustainable over long timescales that are capable of dealing with both exchange rate and funding fluctuations. The creation of the global agreement models necessary to ensure the success of the SKA will address difficult issues of equitable partnership between countries at varying stages of economic and scientific development. This can in turn create best practice models, frameworks and agreements for new collaborations, allowing future projects to move forward in shorter timescales and with much broader participation bases.

Industrial engagement: Industrial engagement is crucial to the overall success of the SKA and cross-national consortia are implicit in the developing procurement policy. To build SKA efficiently and effectively, and to meet the planned decades-long lifetime, will mean challenging industry to develop innovative solutions to drive it, to make it smart, and to ensure its longevity. Many of the solutions of choice will likely be “market-adjacent”: fundamentally based on commercial items, but necessarily occasionally deviating from these standards in order to work efficiently for the project. A legacy outcome of the SKA project for the companies involved will be the retained capabilities, skills and tooling once the SKA is complete, their application to future high-tech contracts and projects, and the creation of new networks of industries and markets in which they may operate.

Human Capital: SKA will contribute significantly to the development of new energy and communication technologies, data processing, science visualisation and imaging, and pioneering technological innovation globally and around each of its science centres. Such developments will benefit the global knowledge-based economy beyond scientific research and academia. For the first time, the countries in the developing world will be active contributors to fundamental research on an unprecedented scale. Emerging and developing countries can become active contributors in the production and exchange of knowledge, stimulating their participation in the global knowledge-based economy. The SKA will need thousands of people from across many countries in a range of professions to design, build and operate it and to run all the associated services: builders, caterers, administrative staff, scientists, engineers, IT specialists, communicators, etc. will be employed in this endeavour. In addition, the existence of the facility will create demand leading to employment opportunities such as tourism around the sites of the telescope and science centres, development of curriculum material related to the SKA, the inspiration of popular culture, etc.

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Question 18: From your perspective, what high level trends will affect the space science sector in the coming years?

For ground based radio astronomy we make the following comments:

Radio astronomers seek not only to study known phenomena in more detail, but to detect and study a wider range of objects at ever-greater distances; the farther the object, the older the signals reaching the Earth today. More distant objects are generally fainter and smaller as seen from Earth, requiring increased sensitivity, resolution and enhanced observational techniques.

Resolution: the laws of physics dictate that a radio telescope with a larger physical size produces higher resolution (sharper) images than a smaller one. By combining the signals from an array of individual antennas, often from observing sessions that extend over a period of time, astronomers can achieve a resolution that is equivalent to that of a hypothetical single antenna of a size equivalent to that of the largest separation between the antennas in the array (the baseline); this technique is known as 'interferometry'. The SKA telescope baselines will range from tens to hundreds of kilometres.

Sensitivity: for a given frequency, measurement bandwidth and duration of observation, the sensitivity of a radio telescope can be increased in only two ways: by improving the efficiency with which the focussed radiation is detected, or by increasing the collecting area of the telescope. In recent years, technological advances have led to detection efficiencies that are near the absolute theoretical limits, so that no dramatic increases in efficiency can be expected. Astronomers can increase sensitivity only by building larger telescopes, or combining ever-greater numbers of such telescopes in interferometric mode to effectively increase the collecting area of the telescope. When fully deployed the SKA will incorporate a receiving surface of a million square metres, fifty times larger than the biggest receiving surface now in existence.

Observational techniques: certain portions of the spectrum at the frequencies of the most important natural emission features have been allocated by international agreement at the International Telecommunication Union for use by radio astronomy and other passive scientific services. These bands are frequently too narrow for some highly sensitive astronomical observations to be completed in a reasonable amount of time. Additionally, the expansion of the universe causes spectral features to be shifted in frequency (the more distant the object, the greater the shift). This effect, known as the "cosmological redshift", moves signals of interest out of the frequency bands currently allocated by the ITU-R to the RAS. Hence techniques for making observations across wider bandwidths, which may also extend past formally defined ITU-R radio astronomy allocations, are in continual development.

Larger projects: in radio astronomy, as in several other fields of science, the trend is toward larger and larger projects out of the funding reach of many individual single countries and we see increasingly wider international co-operation, requiring new organisational models (See also comments on Q17).

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Question 19: For each of the space science application(s) your organisation uses or provides, what are the a) current trends; and b) likely future drivers of demand for spectrum?

Please include in your response:

- the scale of the demand drivers;
- the reason for additional demand (e.g. higher resolution radar data rates/bandwidth required) and whether this increased demand is for data delivery or for the taking of measurements;
- whether increased demand can only be met at specific frequencies and why;
- any variations in demand drivers by geography (i.e. regional or global), and why; and
- whether future demand is expected to be temporary or intermittent, and the reasons for this.

In your response, please provide any evidence which supports your position on the drivers of demand (e.g. forecasts, studies and statistics).

Arrangements for access to spectrum in the SKA's host countries have resulted in the ongoing development of Radio Quiet Zones covering all frequencies currently of interest.

Question 20: Taking into account the drivers you have identified in your response to Question 19 above, what (if any) challenges is your organisation concerned about in meeting potential future demand? Please provide the information by application and band, along with any supporting evidence, if available.

A significant challenge will be maintenance of the integrity of the SKA's RQZs as future telecommunications services are proposed, planned and become operational. From the SKA's perspective of being located in a RQZ, a potential for significant interference issues out of its control reside in the sky. When looking ahead to the next 20 years, we note the possible additional impact from the many proposed new airborne applications and NGSO satellite systems.

Question 21: Are there any future developments, such as the radio astronomy SKA, that could reduce the demand for space science spectrum in the UK?

The SKAO believes that the use of spectrum by ground-based radio astronomy facilities in the UK is not and should not be linked to potential future access to the SKA by UK radio astronomers. The SKA is based in the southern hemisphere and there are many objects of continuing interest in the northern skies that the SKA will be unable to observe. It is also quite possible that to derive optimum benefit to the UK from use of the SKA (and access to its output), that 'spectrum use' by UK observatories might actually increase; consider the following:

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- The EU Written Declaration 45/2011 on 'Science Capacity Building in Africa: promoting European-African radio astronomy partnerships' was made in November 2011.
- The African-European Radio Astronomy Platform (AERAP) was set up in May 2012 as a response to EU 45/2011 to "enable major research and technological advances that will drive socio-economic development and competitiveness in both Africa and Europe". AERAP is now coordinating a strategic cooperation shaped around European investment in science infrastructure; human capital development; ICT and big data; education and public awareness. Some initiatives include:
    - VLBI observations using African and European observatories networked together.
    - UK observatories contributing in real terms to the development of African radio astronomy with "hands-on" programmes in both scientific and engineering areas that are additional to current plans.
- 'Pump priming' UK observing may be needed for the purposes of:
    - Early work to promote observing programmes for the SKA
    - Support observing whilst the SKA is in commissioning & early stages
    - Training of personnel

Question 22: Do you have any comments on the list of potential mitigations we have identified? What likely impact would each of the mitigations have on spectrum demand? To what extent do you believe that these mitigations apply only to certain applications?

For satellite systems, some trends in mitigation may be favourable to radio astronomy (e.g. narrow, rapidly configurable satellite beams) while others may not (e.g. higher power transmissions and the use of phased array antennas that may produce more spill-over in direction and frequency). Also, we should not lose sight of the fact that although this CFI is 'space focussed', ground-based radio astronomy is significantly influenced by potential interference issues with terrestrial and airborne telecommunications systems. Radio astronomy deals with random noise signals, which means that mitigation within the radio astronomy shared bands is very challenging. The ITU-R 'passive' science bands are still of great importance in operations and must be kept emission free.

Generally, increasing spectral purity so that adjacent frequencies receive less energy, improved antenna design and placement, together with real-time dynamic adjustments to use the minimum practicable transmitter power should be a requirement for all systems. Radio astronomy in general and the SKA in particular is committed to complementary mitigations, i.e.:

- use of antennas with tighter sensitivity patterns;
- development of amplifiers, filters and other electronic systems that render a receiver less vulnerable to saturation;
- development of advanced signal processing techniques and algorithms that might allow a significant degree of interference tolerance.

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Question 23: What other mitigation opportunities do you foresee that we should consider? For what applications are these likely to be applicable and what scale of improvement are they likely to deliver?

The commercial industry and astronomy communities usually pursue completely separate goals. Most of the interactions only take place directly within the formal ITU-R Study Groups, where agreement has often been difficult to achieve. New and innovative fora for exchange of information and interaction between these communities should be explored.

Question 24: Beyond the activities already initiated and planned for the space science sector (e.g. as part of WRC-15), do you think there is a need for additional regulatory action that may, for example, help your organisation to address the challenges it faces? In your response, please indicate what type of action you consider may be needed and why, including any evidence to support your view.

We feel that strengthening the enforcement of the existing international Radio Regulations would be desirable. In the past MSS NGSO satellite allocations have been made in adjacent or the same frequency bands allocated to radio astronomy. Due to interference then occurring (which had been predicted), the ability of some radio astronomy observatories to make observations at these frequencies has been compromised. Although formal regulatory procedures for notification and appeals for interference reduction have taken place over several years, little real improvement in the situation is currently seen.

From the SKA's perspective of being located in a RQZ, a potential for significant interference issues out of its control resides in the sky. When looking ahead to the next 20 years, we note the possible additional impact from proposed new airborne applications and NGSO satellite systems. To observe the universe at the farthest reaches of space and time, astronomers now need to extend their observations to wider fractions of the radio spectrum; this goal moves closer for SKA with its terrestrial RQZs. Additional ways could be found to allow astronomers to pursue such observations whilst allowing satellite operators to provide services to customers. One option could be 'Radio Quiet Sky Zones' - controlled satellite (and airborne platform) emission zones over observatories. Terrestrial RQZs have successfully existed for some time, allowing radio astronomy and telecommunications services to co-exist. This concept could be extended to telecommunication systems 'in the sky' that are typically out of the control of individual national administrations. The UK government is asked to consider whether this issue should be explored in the ITU, including whether to include an appropriate item on the agenda at a future World Radiocommunication Conference.

Additionally, the SKAO requests the future support of Ofcom in any matters arising for protection of its operations within the international forum of the ITU.

13th August 2015