Poster at "Exploring the Cosmic Frontier – Astrophysical Instruments for the 21st Century"; Berlin, 18-21 May 2004

Frequency protection for 21st century instruments

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Abstract:

For a fruitful return of the large financial investment foreseen in 21st century astrophysical instruments, these will need to be able to operate in an electromagnetic environment that is increasingly full of man-made interference, driven by commercial pressure. Key scientific goals require very sensitive observations outside the frequency bands allocated for use by radio astronomy – for example for highly redshifted spectral lines. Besides the development of technical methods for the suppression of unwanted interference, concerted efforts are being made to explore specific regulatory protection measures for ALMA and the SKA at the International Telecommunication Union, which regulates the worldwide spectrum use. These efforts are being led by astronomers from IUCAF, the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science of ICSU. They also play a leading role in ITU regulatory studies on the protection of radio astronomy from space and on the possibility and relevance of regulating spectrum use in the sub-millimetre, infrared and optical wavelength domains. Furthermore, the role needs to be explored that the Global Science Forum of the OECD could play in examining the conflicting spectrum needs of astronomers and other spectrum users, like commercial satellite operators, and in recommending practical steps to improve the situation.

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

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.

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 the increasingly fainter required detection levels, and, in the radio domain, increasingly outside the 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 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 always 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.

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.

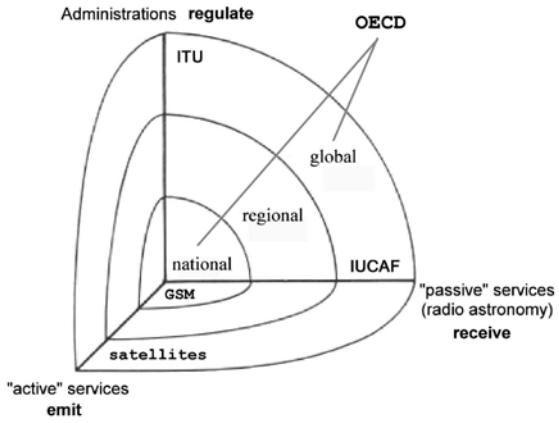
The faint cosmic emissions we want to detect are usually rather noise-like in nature, compared to man-made interference signals. This allows the development of various methods and algorithms to separate the two in the time-frequency-polarisation domain. The ultimate aim is to reject unwanted interference,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

results have been obtained, but no universally applicable interference mitigation method exists, however, and the mitigation of relatively strong signals has its limitations.

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.

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, 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.



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.

Spectrum management in practice – Administrations and astronomers

At a national level: Administrations

The spectrum management process is mainly the responsibility of national 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.

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.

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. The global framework for spectrum management is provided by the Radio Regulations of the ITU, 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.

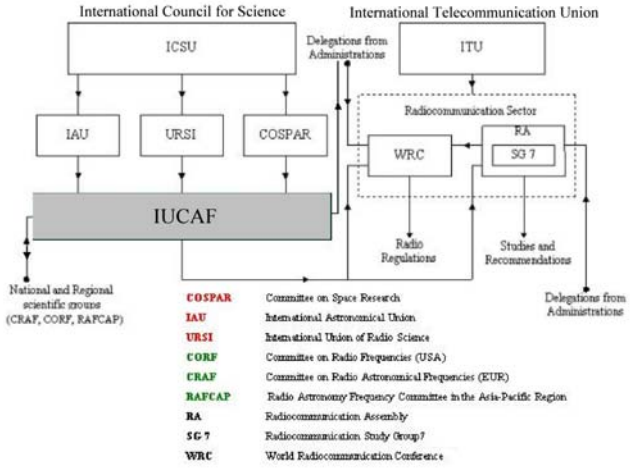
At present, astronomers representing IUCAF attend meetings of ITU Working Parties 4A (fixed satellite service), 7D (radio astronomy) and 8D (mobile satellite service) and Task Groups 1/8 (ultra-wide band devices) and 1/9 (unwanted emissions from satellites), representing 60+ days of meetings per year, excluding numerous national and regional preparatory meetings.

The astronomers involved: 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 by 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.

IUCAF has 13 members, who also play active roles in representing the needs of astronomers at their national Administrations (such as the FCC and the INTA in the USA) and within the regional regulatory coordination bodies (such as the CEPT in Europe), 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.).

IUCAF is organising an expansion in its regional and frequency coverage, through the establishment of groups of Correspondents, from those regions (Africa, South America) where radio astronomy interests are not yet strongly represented in the regulatory circuits, and from optical/infrared observatories, to respond to the ITU decision to expand its regulation of spectrum use to the sub-millimetre, infrared and optical wavelength domains.



The complex structure centred on the ITU is sketched in the Figure to the left. In the left half of the picture one finds different organisations dealing with astronomical research, such as COSPAR, the IAU and URSI, under ICSU, 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 for future giant instruments like ALMA and SKA) and updates of ITU Recommendations.

Current and future issues in spectrum management – enabling astronomical observations

As mentioned above, the ITU has a basic three-year study cycle, between decisions taken at its WRCs (World Radio-communication Conferences). Only issues concerning Agenda Items of the next WRC and issues relating to adopted Questions can be the subject of studies and input documents to the various Working Parties and Task Groups of the ITU.

Key issues on the agenda of WRC-2007 are the consultative process to limit unwanted emissions from satellites into radio astronomy bands, and proposed up- and down-links for mobile satellite systems around the 21cm HI line band at 1.4 GHz, and it is likely that the allocation of frequencies in the range of 275-3 000 GHz

will be on the agenda of WRC-2010. Another issue of great concern to us is the introduction of ultra-wide band (UWB) devices that generally emit at low power, but over a large frequency range, including key radio astronomy bands where "all emissions are prohibited" according to the ITU Radio Regulations.

Regulation at radio frequencies – protection of future giant radio telescopes (ALMA, LOFAR, SKA)

Breakthroughs in astronomical research at radio frequencies are foreseen with the three giant instruments that are presently in their construction phase (ALMA and LOFAR) or planning phase (SKA), for which the total financial investment will be ~2 billion € - which is still considerably less than the cost of a single major commercial satellite constellation.

Their key scientific goals will require ultra-sensitive observations outside the frequency bands currently allocated to the Radio Astronomy Service by the ITU. Inside the allocated bands the levels on interference detrimental to astronomical observations are given in ITU-R Recommendation RA.769 (a.k.a. "Rec 769"), but outside these bands we cannot claim any protection from interference, which will be many orders of magnitudes stronger than the cosmic signals we will try to detect. Although the Rec 769 "hard limit" protection levels are *de facto* included in Footnotes 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 (for commercial reasons).

As mentioned above, national Administrations (Chile for ALMA and the Netherlands for LOFAR) have a large leeway in defining ways and means to protect the sites of these future instruments, but these concern only imposing limits on ground-based transmitters located on their territory – they cannot impose limits on satellites emitting towards the radio telescopes.

The present-day characteristics of the electromagnetic environment in the operating bands of the three new generation telescopes (~0.01-0.24/0.15-22/31-950 GHz = LOFAR/SKA/ALMA) are totally different. The spectrum below 22 GHz is already used intensely for transmissions by a large number of terrestrial and satellite services, and potentially harmful Power Line Transmissions may occur in the frequency range of LOFAR. While the 30-80 GHz range are currently already being considered for future large-scale implementation by active services, future active spectrum allocations above 80 GHz are potentially of great concern for the successful operation of ALMA.

Working towards International Radio Quiet Zones, that include a measure of protection from, or coordination with, satellite systems, requires delicate footwork and meets with strong opposition from commercial satellite operators. IUCAF has assisted with the introduction of Questions within the ITU that allow the start of studies on matters like Quiet Zones and (limitations of) interference mitigation methods, and it will coordinate work on these matters within the ITU, regional bodies and national Administrations. A concern is that negotiating enhanced protection of the sites of a few future giant telescope sites may endanger the protection of existing observatories and the general protection levels of allocated astronomy bands laid down in Rec 769.

Towards regulation at higher frequencies (sub-millimetre, infrared, optical…)

Hitherto, the ITU concerned itself only with regulating spectrum use at radio frequencies, up to 275 GHz (or 1 mm wavelength), but recent developments indicate that the role of the ITU as global body for the co-ordination of spectrum management will be extended over the entire electromagnetic spectrum, as required.

It is foreseen that at the WRC in 2010 frequency allocations will be considered between 275 GHz and 3 000 GHz (100 μm wavelength), and at the WRC in 2003 the ITU decided that studies should be made, and completed by 2007, of the following Question: "What is the possibility and relevance of including in the Radio Regulations frequency bands above 3 000 GHz?". The ITU has allowed that details of systems operating between 275 and 3 000 GHz can be included in the Master International Frequency Register (MIFR), for information purposes – this includes a number of millimetre and sub-millimetre radio telescopes.

IUCAF is preparing actions within the ITU on these issues, and is organising a group of Correspondents from observatories operating at infrared and optical wavelengths – specifically, the astronomical community should express itself on the possibility and relevance of the regulation of the spectrum below 100 μm wavelength: what would we like to be regulated, and how? A first example of dealing with possibly harmful interference from inter-satellite communication lasers is mentioned below.

It seems clear that the inclusion of infrared and optical wavelengths in the ITU Radio Regulations is still remote, but the process starts with providing information on astronomical systems and the characteristics that

can be used to regulate their frequency protection. We need to consider the benefits and feasibility of creating analogies with Radio Quiet Zones – the establishment of Optical Dark Zones (?) around optical observatories – and an optical equivalent of the workhorse ITU-R Recommendation 769 that gives levels of interference detrimental to radio astronomical observations in bands allocated to the Radio Astronomy Service – defining maximum sky brightness levels due to man-made emissions in bands allocated to the (Optical) Astronomy Service…

Space-borne observations – radio and infrared/optical

Concerning radio astronomy from space, at present the ITU Radio Regulations only provide regulations on frequency protection for space-VLBI radio observations in a small number of specific bands used for such observations. IUCAF is coordinating efforts towards the drafting of a new ITU Recommendation on protection criteria for radio astronomical observations from space. The first step involves characterising the relevant parameters of space-born radio telescopes, which are still very few in number below 275 GHz (VSOP, RADIOASTRON), the current upper limit of the frequency range regulated by the ITU. High-frequency space-born telescopes like Planck will be considered under the expansion of the scope of the ITU Radio Regulations towards higher frequencies (see above).

Concerning the protection of astronomical and Earth Exploration observations made from the Earth and from space from inter-satellite communication lasers studies were made in the period 2000-2003, which resulted in an ITU Recommendation on this issue. Since systems operating at these unregulated frequencies cannot yet be registered at the ITU, it was decided that a register of such laser systems be kept by the Space Frequency Coordination Group (SFCG), which gathers national and international space agencies and where IUCAF has observer status, with IUCAF as liaison to the IAU on the proliferation of these systems.

Another route – 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 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:

- 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.