Preserving the Astronomical Sky
IAU Symposium, Vol. 196, 2001
R. J. Cohen and W. T. Sullivan, III, eds.

Radio Astronomy and the Radio Regulations

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Abstract. This article gives a brief introduction to the status of radio astronomy within the International Telecommunication Union (ITU), the body which coordinates global telecommunications. Radio astronomy entered the ITU arena in 1959 as a relative latecomer. By its nature, radio astronomy does not fit into the ITU system very well: regulators are hoping to facilitate commercial development of the radio spectrum, whereas astronomers are hoping to retain quiet frequency bands through which to study the Universe at ever higher sensitivity. Nevertheless there are major long-term goals which radio astronomers can realistically hope to achieve via the ITU in the years ahead, including more favourable frequency allocations and better regulatory protection. The prospects for radio astronomy at the forthcoming World Radio Conference WRC-2000 are reviewed. It is vital that radio astronomers participate in force at this WRC.

1. Introduction

I am proud to be a radio astronomer. During my scientific career the typical measurement sensitivity has increased nearly a million-fold, from a tenth of a Janksy to microJanskies, and the angular resolution by a similar amount, from arcseconds to tens of microarcseconds. Radio astronomy now achieves the highest sensitivity and the highest angular resolution of any branch of astronomy, and it does so relatively cheaply using ground-based facilities (Kellerman 1997). But we face growing problems of radio interference which threaten to halt or even reverse the steady advances we have enjoyed (Cohen 1999).

Once radio astronomers had the radio spectrum more or less to themselves and any interference problems were local. The electrification of the railway line which passes my observatory, Jodrell Bank, was big news forty years ago, but it did not affect other radio observatories. Today the radio spectrum is crowded and we face global threats from satellites. Our experiences with the GLONASS satellite system showed just how effectively a branch of radio astronomical research could be halted worldwide by just a few small satellites (Galt 1990, Ponsonby 1991, Combrink, West & Gaylard 1994). Nowadays more than 100 satellites are launched each year and there are plans for thousands more, covering ever more bandwidth. The radio spectrum has become big business.

Radio astronomy does not really fit in alongside the telecommunication industry. The cosmic signals we study are extraordinarily weak and we usually

https://doi.org/10.1017/S0074180900164137 Published online by Cambridge University Press

have to observe them in the presence of much stronger manmade signals. It is exactly like trying to observe sources as faint as stars while there are many other sources as bright as the Sun in the sky. Cosmic sources are usually noise-like and their power levels and frequencies are fixed by nature. Because we are conducting research, the outcome of the measurements cannot be predicted in advance, so we are particularly vulnerable to interference. We can only survive the telecommunication revolution if commercial developments are well regulated.

The rules governing the use of radio are made by the International Telecommunication Union (ITU), a body which began as an intergovernmental organization, but which is increasingly influenced by multinational corporations. In this article I explain something about the nature of the ITU, and the status of radio astronomy within the ITU framework. I also highlight some of the problems which are developing, and raise the question of whether we need to be looking outside the telecommunication community to get protection for our work.

2. The International Telecommunication Union

The ITU was established long before radio astronomy existed. Its origins can be traced back to the first International Telegraph Convention of 1865, which set up the International Telegraph Union, with 20 member countries. As communications evolved so did the acronym. Since 1934 "ITU" has meant the International Telecommunication Union and since 1948 the ITU has had its headquarters in Geneva. Today the ITU is an intergovernmental organization within which governments and the private sector coordinate global telecommunication networks and services.

The modern ITU has a complex structure with three sectors (Radiocommunication, Telecommunication Standardization and Telecommunication Development), all governed by the Plenepotentiary Conference. The Radiocommunication Sector, ITU-R, holds World Radio Conferences (WRCs) at which the Radio Regulations are agreed and revised. The Radio Regulations set out rules for use of the radio spectrum. The regulations are a kind of treaty between nations, to allow everyone to use the radio spectrum without getting in each others' way. The basic principles underlying the regulations are to respect your neighbours' use of the spectrum and to respect existing radio services when introducing new services or other changes to the Radio Regulations.

The Radio Regulations contain legalistic definitions of telecommunication, radiocommunication, radionavigation, harmful interference, and so on. The ITU divides the world into three regions for administative purposes: Europe and Africa are in Region 1, the Americas in Region 2, and the Asian-Pacific countries in Region 3. The radio spectrum up to 275 GHz is divided into frequency bands which are allocated to various radio services. Allocations can have primary or permitted status, or secondary status, and both the allocations and the allocation status can vary between regions. The regulations are further qualified by footnotes which can spell out different categories of service within specific countries, or special conditions attached to the use of certain frequency bands by certain services. It is a legal maze.

3. Radio Astronomy in the Radio Regulations

Radio astronomy entered the Radio Regulations in 1959, when it was defined in Article 1 as "astronomy based on the reception of radio waves of cosmic origin". The radio astronomy service also received its first frequency allocation at this time: the frequency band 1400-1427 MHz containing the 21-cm line of neutral atomic hydrogen (HI). This was the first frequency band to be set aside by the ITU purely for passive use. A new footnote was added stating that "all emissions in the band 1400-1427 MHz are prohibited". Nowadays the radio astronomy service has many frequency allocations, totalling 2% of the radio spectrum below 50 GHz (the part that is used for telecommunications) and 24% of the (largely unexploited) spectrum from 50 to 275 GHz. Radio astronomy interest in further frequency bands from 275 to 400 GHz is also noted.

The regulatory status of our allocations is far from ideal, however. What we want to have is frequency allocations with primary status shared only with other passive services. One third of our allocations are of this type, but the other two thirds are shared with active services. Furthermore, there is no mandatory protection for radio astronomy as there is for most other services.

Technical criteria for protecting radio astronomy measurements against interference from transmitters used by other radio services are developed within study groups and task groups of the ITU-R. Working Party 7D (radio astronomy) has produced a Handbook on Radio Astronomy and a set of Recommendations which are described in the following section. As yet, none of these recommendations has regulatory status. The Radio Regulations specify in precise detail how an earth station for telecommunciations should be protected, but not a radio astronomy station. The protection levels for radio astronomy do not appear anywhere in the Radio Regulations. In fact the very concept of harmful interference, on which regulatory protection would be based, is not even defined for the radio astronomy service.

Nevertheless the ITU system could accommodate some of our hopes and aspirations if the political will existed. For example, radio-quiet zones could be set up right now to protect major facilities from terrestrial transmitters. The Radio Regulations are not completely prescriptive: a country has the right to use the radio spectrum how it likes within its own borders, provided that it does not cause interference in other countries where the Radio Regulations are being obeyed. This means that a geographically large country could, if it chose, establish a radio-quiet zone for radio astronomy right now. This would cause no interference to any other country. A measure like this could protect a major terrestrial radio observatory from all transmitters except those on satellites and space stations: it would represent a major safeguard for the future of our science.

4. ITU-R Recommendations on Radio Astronomy

At the present time there are eight ITU-R Recommendations on Radio Astronomy and one in press:

Rec. ITU-R RA.314-8 Preferred frequency bands for radioastronomical measurements

https://doi.org/10.1017/S0074180900164137 Published online by Cambridge University Press

Rec. ITU-R RA.1031-1 Protection of the radio astronomy service in frequency bands shared with other services

Rec. ITU-R RA.517-2 Protection of the radio astronomy service from transmitters in adjacent bands

Rec. ITU-R RA.611-2 Protection of the radio astronomy service from spurious emissions

Rec. ITU-R RA.1237 Protection of the radio astronomy service from unwanted emissions resulting from applications of wideband digital modulation

Rec. ITU-R RA.769-1 Protection criteria used for radioastronomical measurements

Rec. ITU-R RA.1272 Protection of radio astronomy measurements above 60 GHz from ground based interference

Rec. ITU-R RA.479-4 Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon

Rec. ITU-R RA.*in press* A radio-quiet zone in the vicinity of the L_2 Sun-Earth Lagrange Point

Rec. ITU-R RA.314-8 concerns frequency bands for radio astronomy. There are three important tables in the annex to this recommendation, listing frequency bands of greatest astrophysical interest for spectral line measurements below 275 GHz, for spectral lines from 275 to 811 GHz, and for continuum measurements. The IAU periodically reviews these tables through a working group of Commission 40, Division X (Radio Astronomy) and communicates the proposed revisions to Working Party 7D via IUCAF (the Scientific Committee on the Allocation of Frequencies for Radio Astronomy and Space Science, which is described by Robinson elsewhere in these proceedings). The ITU really does pay attention to the tables. For example, as soon as the methanol line at 6.668 GHz was discovered to be a powerful maser (Menten 1991), it was added to the Table of Astrophysically Important Spectral Lines by the IAU in Buenos Aires, July 1991, passed to the ITU-R at the next meeting of the ITU-R Working Party on Radio Astronomy, and it is now listed in the Radio Regulations in Footnote S5.149. *Recommends 5* of Rec. ITU-R RA.314-8 also highlights the issue of spectral lines outside allocated bands and recommends that administrations be asked to help coordinate radio astronomy observations of spectral lines outside the allocated bands.

Rec. ITU-R RA.769-1 provides general protection criteria for the radio astronomy service. The specific recommendations give the substance to my earlier remarks about let-out clauses (my emphasis added):

1. *Radio astronomers should be encouraged to choose sites as free as possible from interference;*

2. *Administrations should afford* ***all practicable*** *protection to frequencies used by radio astronomers in their own and neighbouring countries, taking* ***due account of*** *the levels of interference given in Annex 1;*

3. *Adminstrations, in seeking to afford protection to particular radioastronomical observations, should* ***take all practicable steps to*** *reduce to the absolute minimum, all unwanted emissions falling within the band of frequencies to be protected for radio astronomy, particularly those emissions from aircraft, spacecraft and balloons;*

4. *When proposing frequency allocations, administrations should* ***take into account*** *that it is very difficult for the radio astronomy service to share frequencies with any other service in which direct line-of-sight paths from the transmitters to the observatories are involved. ...*

The interference levels given in Annex 1 of Rec. ITU-R RA.769-1 are only advisory. Most people take them seriously, however, and they usually form the starting point for negotiations about protection of radio astronomy. The interference analysis on which the Recommendation is based assumes that the interfering signal enters the radio astronomy system through far sidelobes with 0 dBi gain, i.e. it takes no account of the possibility that the interfering source could be near the main beam of the radio telescope (as might be the case for a satellite).

Rec.1031-1 deals with shared frequency bands. The annex, which you will probably guess by now is the best part, contains a description of coordination zones which can be establised around radio observatories to protect them from terrestrial transmitters. The coordination zone concept could be the seed from which radio-quiet zones will one day spring.

The annex to Rec.1031-1 also gives guidelines on how to calculate the appropriate size for such a coordination zone, depending on details of the tranmsitters. A typical size is 500 km. One of the parameters needed for the calculation is a percentage of time for which the interference levels of Rec.769-1 should not be exceeded due to variable propagation. The figure of 10% which is given there has come to be reinterpreted by the telecommunication community as an acceptable percentage of data-loss for the radio astronomy service, whether in shared bands or passive bands. Radio astronomers within ITU-R Working Party 7D are currently trying to clarify this misunderstanding.

5. ITU-R Handbook on Radio Astronomy

The ITU-R Handbook on Radio Astronomy (1995) is a useful source of further information on the radio astronomy service within the ITU-R. Its nine chapters complement the ITU-R Recommendations, often giving the rationale behind them. For example, Chapter 3 on Preferred Frequency Bands for Radio Astronomy Observations (corresponding to Rec. ITU-R RA.314-8) is preceded by a chapter on Characteristics of the Radio Astronomy Service, which sets out the nature of the emissions we study and the physical reasons for the frequency allocations we seek. Chapter 4 on the Vulnerability of Radio Astronomy Observations to Interference contains, in addition to the interference thresholds, much additional material on the derivation of interference criteria in special cases, for example interferometry. Chapter 5 on Sharing the Radio Spectrum with Other Services includes band-by-band discussions of typical interference scenarios, including typical sharing parameters for terrestrial transmitters and

https://doi.org/10.1017/S0074180900164137 Published online by Cambridge University Press

necessary separation distances. Chapter 6 on Interference to Radio Astronomy from Transmitters in Other Bands includes detailed discussion of both sides of the electromagnetic compatibility problem: how radio astronomers can best protect themselves against strong signals in adjacent or nearby frequency bands, and levels to which such transmitters need to reduce their unwanted emissions into the radio astronomy bands. Particular threats which are discussed include transmitters on aircraft or spacecraft and transmitters using wideband modulation schemes.

A chapter on special applications deals with VLBI including space VLBI and geodesy, pulsar observing techniques, solar observations, and radio astronomy from Antarctica and from space. There are also chapters on the Search for Extraterrestrial Intelligence (SETI) and on ground-based radar astronomy.

The first edition of the Handbook was published in 1995. It was based on material taken from Reports which were already several years old at that time. A new edition of the Handbook is urgently needed.

6. Getting Involved

There is one official mechanism to ensure that radio astronomers attend meetings of ITU-R and participate in the work of its study groups and task groups: IUCAF, the Scientific Commission on the Frequency Allocations for Radio Astronomy and Space Science. IUCAF was founded in 1960 as an Inter-Union Commission, with members drawn from IAU, URSI and COSPAR (Robinson, 1999). IUCAF membership is restricted to 15 persons, but many more radio astronomers are actively supporting IUCAF, as email correspondents. IUCAF acts as a network to coordinate the efforts of radio astronomers in many countries.

Within individual countries it is up to radio astronomers to make themselves known to their national adminstrations and up to the administrations to then support the astronomers' participation in ITU-R meetings as national delegates. The work is done on a voluntary basis, usually financed from the radio observatory budget. We need more volunteers for this work and more support from observatory directors. It costs money and time. My own observatory already contributes more than 2% of its budget on this work and the pressure is steadily increasing.

Since 1991 some North American countries have sent employees of, or consultants for, companies like Motorola as national delegates to the meetings of Study Group 7 (radio astronomy). ITU-R working parties must reach concensus on the output they produce. On several occasions this has meant that the wishes of the radio astronomy community have been blocked in WP7D by someone in the pay of a satellite corporation. If this situation is not to develop into a wasteful confrontation, we need more radio astronomers to become involved in the task of explaining our needs to other radio users and convincing them that it is in the best interest of all parties to protect our work.

The telecommunications revolution cannot be stopped. But neither is it automatically a bad thing for radio astronomy. New technology has already given us more sensitive receivers, and in future could deliver cleaner radio transmitters and new signal-processing techniques for dealing with interference.

7. What Do We Want?

Radio astronomers need to be very clear about their objectives before going into battle in the ITU-R arena. We should only ask the ITU for things the ITU member countries can actually give us. In my view we need some of the frequencies all of the time, as we have been asking since 1959, but we also need access to all of the frequencies some of the time.

Officially allocated passive frequency bands are vital to guarantee successful radio astronomy operations anywhere in the world. The most fundamentally important spectral lines, such as the 21-cm hydrogen line, must be accessible globally, by amateurs as well as professionals. There are centuries of work to be done mapping out the structure of our Galaxy using modest telescopes, even just for the protected spectral lines. We also need global allocations throughout the spectrum for continuum observations. There are no all-sky continuum surveys at high angular resolution above 5 GHz. And of course VLBI would be impossible without global allocations.

But in addition to these fundamental needs we also require access, on a best efforts basis, to the *entire* radio spectrum. No one has yet found the right words to explain this to the ITU. Yet our science will slowly wither if all radio telescopes end up confined to the officially allocated frequency bands. The expansion of the Universe produces redshifts of the spectral lines to lower frequencies. The more distant the source the fainter will be its radio emissions and the further they will be from their rest frequency. We need to develop ways to access the redshifted lines anywhere in the radio spectrum. We also need larger bandwidths than those officially allocated for a second reason: to improve the sensitivity of our continuum measurements. Access to wider bands is not impossible. Individual countries are sometimes prepared to take action within their own borders to protect a large-scale radio facility on a special site. We will need to persuade them to do the same for new-generation radio astronomy instruments.

New satellite services are also moving towards wider bandwidths to offer Internet-in-the-sky and live video connections to mobile users. Satellite are a global threat. They can block out large frequency bands and they can be visible from anywhere on the Earth's surface. Unwanted emissions from satellites often mean that the bands denied are far bigger than what is actually used by the satellite service.

Ideally no frequency band should be closed permanently on the Universe. Scientists of the world should have access to all radio frequencies for at least some of the time from at least some places on the Earth's surface. This is not an unreasonable goal.

8. World Radio Conference 2000

WRC-2000 will be of paramount importance to radio astronomy (Ruf, these proceedings). Radio astronomy issues appear at many places in the WRC-2000 Agenda, the most important being items 1.2, 1.4, 1.5, 1.11, 1.14, 1.15.1, 1.16, and of course item 7.2, which sets out the agenda for future conferences.

The issue of unwanted emissions from satellites comes up under agenda item 1.2. Task Groups 1/3 and 1/5 have been working for 4 years 'to finalize remaining issues in the review of Appendix **S3** to the Radio Regulations with respect to spurious emissions for space services, taking into account Recommendation **66'**. Task Group 1/5 will recommend the first limits to unwanted emissions from spacecraft. This is the vital first step towards protecting radio astronomy from future flotillas of telecommunication satellites. The limits being proposed at this time do not provide all the protection we need, but they are far better than no limits at all, and they can be tightened in future as technology improves.

There are several items dealing with allocations for satellite downlinks in frequency bands dangerously close to radio astronomy bands, where the issue of unwanted emissions spreading into radio astronomy bands is especially relevant. Agenda item 1.4 concerns, among other things, allocation to the fixed satellite service (space-to-Earth) in the band 41.5-42.5 GHz and protection of the radio astronomy service in the adjacent SiO band 42.5-43.5 GHz. Agenda item 1.5 concerns high-altitude platforms (HAPs). These are essentially stratospheric balloons, comparable in their coverage to satellites, with the potential to cause interference to radio astronomy stations over a wide area. Agenda item 1.11 concerns, among other things, a possible allocation of the band 405-406 MHz for a satellite downlink, close to the radio astronomy band 406.1-410 MHz. Agenda item 1.14 concerns the feasibility of a satellite downlink in the band 15.43-15.63 GHz, very close to the passive band 15.35-15.40 GHz. Agenda item 1.15.1 concerns a possible satellite downlink for a new-generation satellite navigation system, just above the radio astronomy band 4990-5000 MHz,.

Arguably the most important item for radio astronomy, however, is item 1.16, 'to consider allocation of frequency bands above 71 GHz to the earth exploration satellite (passive) and radio astronomy services ... '. The last frequency allocations to radio astronomy at millimetre wavelengths were made in 1979, when mm-wave astronomy was still in its infancy. WRC-2000 gives us our first opportunity in 21 years to obtain new mm-wave allocations and to review the existing allocations to radio astronomy.

We need to send a strong delegation to WRC-2000, at least 14 radio astronomers, to lobby their national administrations and to cover all the parallel sessions where the detailed arguments need to be won.

9. Conclusions

As use of the radio spectrum grows throughout the world, radio astronomers could find themselves increasingly confined to the frequency bands officially allocated by the ITU-R. But the science we are trying to do demands much more than this. We need to use wider frequency bands to search in redshift and to maximize the sensitivity of our continuum measurements. A major goal for the next century is to ensure that the best facilities retain access to large tracts of radio spectrum, at least for some of the time.

We also need to protect new instruments, such as ALMA and the SKA, and we need to find the right way to protect special sites, ranging from radio-quiet zones on the Earth, to those in space such as the Sun-Earth Lagrangian point L_2, where PLANCK and other sensitive instruments are planned to operate. The ITU-R Recommendations on these issues are only just the first steps towards guaranteeing the success of these and other new instruments.

We must also continue efforts to keep our allocated frequency bands clean. In particular, the way in which unwanted emissions from satellites can be reduced is a big field waiting to be explored. The satellite community has so far not shown itself strongly minded to tackle the problem, so the push may need to come from higher up. The long-term goal is to achieve regulatory protection of the passive bands to a stated level of power flux density at the surface of the Earth. The technology to achieve this exists today: the problem we face is how to persuade the telecommunications community to help us.

Today the mm-wave bands are clean. It is not clear to me how to keep them that way. The fact that radio astronomy already has 24% of the mm-wave frequency allocations probably means that the rest of the world will be reluctant to give us any more exclusive allocations. Perhaps there are other ways to keep the mm-wave bands clear at special sites, while exploiting the bands for telecommunications in built-up areas. Perhaps the short range of mm-wave transmitters and the efficient blocking by buildings and walls will suffice to keep the observatories quiet. In any case we must keep access to large tracts of the millimetre spectrum, which is so incredibly rich in molecular lines.

Radio astronomy is inevitably a small player within the ITU-R. We need to win powerful friends to succeed. Education is needed at all levels. We have a big story to tell: the origins and evolution of the Universe. It is a story the public likes. The UNISPACE-III meeting with which our symposium is associated is an important step in raising awareness. For the first time the need to keep our radio window on the Universe clear will be discussed at the highest level possible on our planet.

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https://doi.org/10.1017/S0074180900164137 Published online by Cambridge University Press