Better Protection for Radio Astronomy at Millimetre Wavelengths

J. B. Whiteoak & A. Tzioumis
CSIRO Australia Telescope National Facility, Epping, NSW, 1710
E-mail: John.Whiteoak@atnf.csiro.au

Abstract
The International Telecommunication Union (ITU) regulates the usage of the radio spectrum. In May 2000 it will hold a World Radio-communication Conference (WRC-2000) in Istanbul to revise the ITU Radio Regulations with an aim to introducing revised requirements for planned spectrum usage in a form which is, as far as possible, mutually acceptable to the representatives of participating countries. WRC-2000 promises to provide far-reaching, improvements in the future protection of astronomy observations at millimetre wavelengths.

We are our own worst enemies
It is rather ironic that we mortals, who in less than half a century have had the ingenuity to develop the means to push back the frontiers of radio astronomy almost to the beginning of the Universe around us, have, at the same time, produced the means to threaten the very future of the science. Without careful planning, the services that today we regard as absolutely essential to improve or even maintain our quality of life – services such as broadcasting, television, mobile telephones, and even worldwide navigation systems – will swamp forever the signals reaching our plane from the near and far reaches of the Universe. On the other hand, by careful international negotiations with the other users of the radio spectrum, it might be possible to ensure that radio astronomy is sufficiently protected, not only for our children, but also for our children's children.

Britannia does not rule the radio waves – the ITU does
The radio spectrum is a unique precious resource which must be shared equitably amongst many services in many countries. On an international scale the regulation of usage of the spectrum is organized through the International Telecommunications Union (ITU), a specialized agency of the United Nations organization. Every few years, the Radio-communication Sector (ITU-R) of the ITU holds a World Radiocommunication Conference (WRC) to revise the ITU Radio Regulations, which are the basis of the planned usage of the spectrum. The revisions provide for the minimisation of interference between the radiocommunication services sharing the spectrum, the implementation of new systems and services, the harmonisation of usage by countries worldwide, and the promotion of worldwide standards for systems and equipment. The results of each Conference, the Final Acts, have the status of an international treaty. However, as in most areas of international law, enforcement of the Regulations is difficult. and depends largely on the goodwill of the participants.

The Agenda of each WRC are set several years in advance, to enable the preparation and compilation of technical and other information on which decisions will be made. There are several conduits by which the information reaches the WRC. The ITU-R regularly holds a Radiocommunication Assembly (RA) which manages a set of Study Groups (SGs) representing individual radiocommunication services. The SGs meet annually and by means of Working Parties and Task Groups which meet more frequently, study set questions and prepare responses mainly in the form that at the RA level become ITU-R Recommendations on such issues as preferred frequencies, protection criteria, sharing between services, etc. The recommendations provide a body of technical, operational and regulatory/procedural inform-

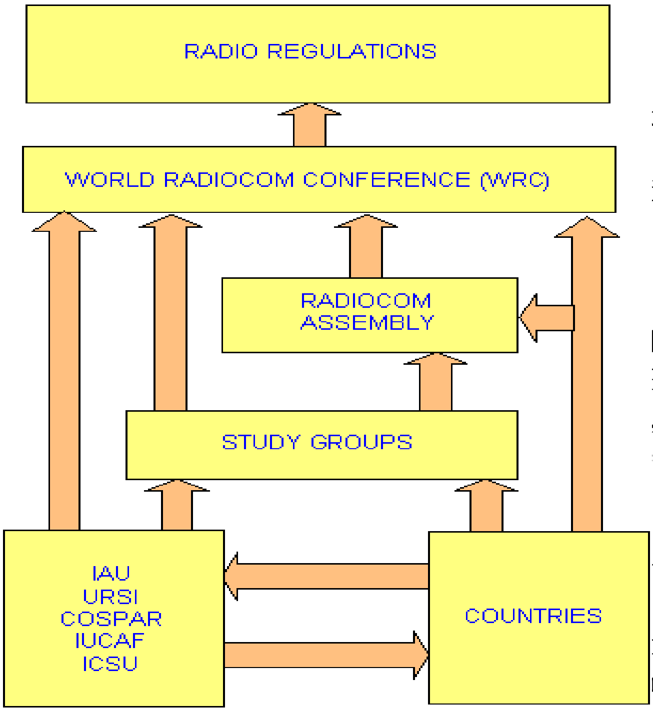


Fig.1 Routes ... Regulations

ation that has been ... are used to provide appropriate inputs to ... generally regarded as authoritative guidelin...

Other inputs to the ... ls from participating administrations, each ... RC. Submissions can also be made by ... , regional and other international organiz... d agencies, but these groups have no votin...

To protect the opera... trum, the services are 'allocated' frequency ... table of allocations as a direct listing or wi... ocation, the world has been divided into thr... northern Asia; Region 2 includes North and South America; and Region 3 includes Australasia and southern Asia. For any particular frequency band, the allocations may differ in different Regions. Bands are often shared between two or more services that can operate at similar frequencies without interfering with each other. Generally speaking the allocations are designated 'primary' or 'secondary'; a service with a secondary allocation is not permitted to cause interference to a service with a primary allocation in the same band. Participating administrations retain sovereign spectrum rights within their national boundaries, and can deviate from the international regulations as long as this does not cause harmful interference within the territories of other administrations. Within individual countries, spectrum management matters are handled by government agencies. In Australia the agency is the Australian which Communications Authority, (ACA), issues the Australian Radiofrequency Spectrum Plan [1] containing the international allocations plus Australian allocations.

Radio astronomy requires frequency bands protected from man-made emissions, and therefore must be involved in ITU frequency sharing procedures. Accordingly, since 1959, for spectrum management purposes the ITU has recognized radio astronomy as a radiocommunication service. Within the ITU its affairs are managed by Working Party 7D (chaired by Australia) of ITU-R Study Group 7 (Science Services), which has an Australian Vice-Chairman. The Working Party has prepared a Handbook on Radio Astronomy [2] dealing with those aspects of radio astronomy relevant to frequency coordination.

Radio astronomy observations are not easy

<u>Radio signals from the cosmos are very, very faint.</u> It is no accident that radio astronomers use the largest radio antennas or groups of antennas. The radio signals reaching us from distant objects in our own and other galaxies can be incredibly faint, and can only be detected using radio telescopes with extremely large collecting areas. Signals with typical spectral power flux densities as low as –320 dB(W m^{-2} Hz^{-1}) are currently being detected, and not unexpectedly, even fainter signals are being sought as astronomers probe the far reaches of the

Universe. The forces of gravity foil our attempts to build high-performance, fully steerable radio telescopes with ever-increasing parabolic collecting areas: diameters of about 100 metres appear to be a practicable limit at the moment. However, we can still increase our collecting area by building large collectors on the ground (such as the 1000-ft diameter telescope in a valley in Puerta Rico), or by harnessing large groups of antennas into giant arrays (the Australia Telescope Compact Array is a smaller version). The latter can provide us with total collecting areas much larger than possible with single antennas. Another important advantage of arrays is that by spreading the individual antennas further and further apart, radio astronomers can make images of radio sources with finer and finer detail. Accordingly, we now have large VLBI (very long-baseline interferometry) arrays extending not only across continents or from continent to continent, but from Earth to an orbiting antenna. For next-generation systems, two large arrays are being considered internationally – the cm-wave Square Kilometre Array (SKA) and the mm/sub-mm wave Atacama Large Millimetre Array (ALMA).

<u>Radio astronomy requires observations at many different frequencies.</u> Ground-based radio astronomy observations are made at frequencies in the range 1 MHz – 1,000 GHz. At low frequencies, observing is limited by the Earth's ionosphere. At frequencies above 20 GHz, absorption by oxygen and water vapour in the Earth's atmosphere restricts observations to atmospheric 'windows' between the frequencies of the absorbing molecular lines.

The radio emission of interest to astronomers falls into two well-defined classes:

- wideband 'continuum' radiation extending over octaves in frequency. 'Non-thermal' emission occurs as 'synchrotron' radiation from electrons moving at high speeds in magnetic fields or as plasma emission resulting from the scattering of plasma waves. The former is detected in the central regions of galaxies, or as large, extended lobes extending outwards from galaxies. 'Thermal' emission is radiated by hot neutral and ionized gas (a signpost to stellar nurseries where stars have just been born), stars, planets, and the widespread cosmic microwave background (CMB) believe to be a relic of the 'Big Bang'.
- narrow-band 'spectral- line' radiation, with bandwidths as low as a kilohertz. This radiation is produced in dense interstellar gas clouds and dense stellar envelopes by atoms and molecules when they lose or gain energy by colliding with each other or by 'excitation' by nearby sources of radiation. Each atom or molecule produces a unique set of spectral lines with specific frequencies. Although these frequencies are set by molecular or atomic structure, the frequencies observed from the interstellar medium are 'Doppler' ('red') shifted by the velocity of the molecules or atoms towards or away from the observer. Several thousand spectral lines from more than a hundred molecules or atoms have been detected.

<u>A radio astronomer's lot is not always a happy one!</u>
Radio astronomy signals are very weak, with power flux densities typically 40 to 100 dB below those utilized by most other services. Because of this, radio astronomy is potentially very susceptible to interference from transmitting ('active') services with which it shares the radio spectrum. Although the Radio Regulations contain no threshold levels for interference that is detrimental to radio astronomy, one of the radio astronomy recommendations produced by Study Group 7, Rec. ITU-R RA.769 [3], contains lists of threshold levels, and these have been adopted by some other services in 'coordination' procedures involving radio astronomy and these services. For continuum observations, the listed harmful interference levels of spectral power flux density vary smoothly from –259 dB(W m^{-2} Hz^{-1}) at 151 MHz to –213 dB(W m^{-2} Hz^{-1}) at 270 GHz. These values were, however, derived for the isotropic-aerial

case, and are appropriate only where the gain of an antenna's beam pattern is 0 dBi or lower. Consequently, even if these conditions were satisfied, radiation arriving at an antenna from a direction less than about 20^{o} from the beam boresight would cause harmful interference.

Radio astronomy requires a large amount of protected radio spectrum, but must share the spectrum with many other services. For studies of continuum emission, wide bands are needed spaced at about octave intervals in frequency. In previous times when the first allocations were made, radio astronomy receivers had bandwidths of only a few MHz, and bandwidths were allocated accordingly and are far less that today's wideband receiver systems. As an example, the protected band centred on 2695 MHz has a band of only 10 MHz, compared with the bandwidth of 128 MHz that is generally used for continuum observations with the Australia Telescope Compact Array. Observing with such systems can (and does!) lead to interference from transmitters in bands adjacent to the narrow protected bands.

Spectral-line observing poses other problems. Whereas continuum bands do not require specific frequencies, spectral-line frequencies are set by nature and therefore require specific frequency bands. Moreover, the Doppler frequency shifts must be taken into account when observing gas clouds with different line-of-sight velocities. For instance, for observations of the clouds in our Galaxy, allowance must be made for frequency variations of about +/-0.1%. As galaxies become more and more distant, their velocities increase systematically, and their associated spectral-lines have progressively lower frequencies. As an example, in the detection of carbon monoxide (CO) gas from some far distant galaxies, the CO lines were Doppler-shifted from 115 GHz to below 40 GHz. The results emphasize that in looking back into the early Universe, large regions of spectra need to be accessed. Unfortunately, particularly at lower frequencies, radio astronomy is allocated only a small fraction of the spectrum – for instance 1% below 20 GHz. Although current allocations protect the 'rest' frequencies of the most astrophysically important molecules (these are listed in Recommendation ITU-R RA.314 [4]), there is little protection for large Doppler-shifted frequencies. In addition, because most of the radio astronomy allocations occurred at the 1979 World Administrative Radio Conference (WRC-79), there is no protection for important spectral-lines that have been detected since this meeting. Unfortunately, the low-frequency end of the radio spectrum is now so occupied with other services that it would be difficult for radio astronomy to obtain further allocations there.

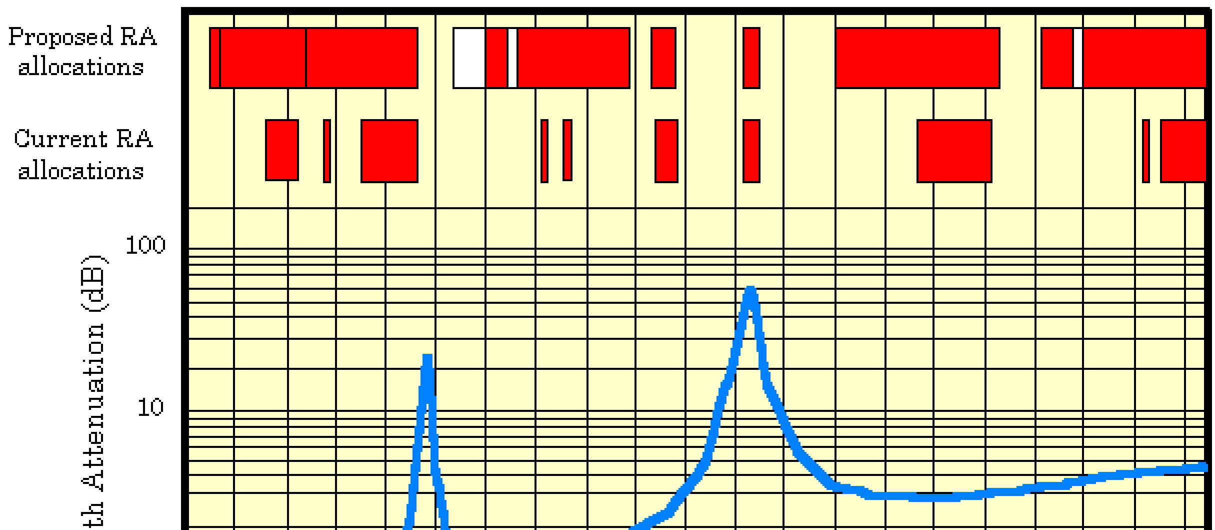
Radio astronomy can share its allocated bands with other 'passive' services, and to some extent with Earth-based fixed and mobile services following appropriate 'coordination' procedures. However, it cannot share with satellites that transmit Earthwards. Irrespective where a radio telescope is pointing, if such a satellite is above the horizon of the telescope, its transmissions will ruin the radio astronomy observations. Moreover, the bands allocated to radio astronomy are not always free from harmful interference. 'Unwanted' emissions can be produced by transmitters in bands adjacent to radio astronomy bands or even in bands that are harmonically related to the radio astronomy bands. The protection levels listed in the Radio Regulations fail by factors of up to three orders of magnitude to adequately limit the overflow.

Big wins for radio astronomy at WRC-2000?

The protection of radio astronomy should take a giant leap at WRC-2000. For the first time since 1979 there will be an opportunity to improve radio astronomy allocations, even if only in the high frequency range 71 – 275 GHz. This range contains three atmospheric 'windows' in the approximate ranges 71 – 115 (3-mm band) GHz, 125 – 170 GHz (2-mm band), and 200 – 275 GHz (1.3-mm band). Several millimetre and sub-millimetre radio telescopes around the world (including the Australia Telescope's 'Mopra' facility near Coonabarabran and the appropriately upgraded Compact Array near Narrabri) can operate in frequency bands covering one or more of the windows. Just about all molecular lines have frequencies above 70 GHz, and over two thousand have been detected between 71 and 275 GHz.

At present, the windows contain only a limited number of radio astronomy allocations protecting the important interstellar molecule carbon monoxide and a handful of other molecules. Consequently, about two years ago ITU's Working Party 7D, working together with the Inter-Union Committee on Frequency Allocations for Radioastronomy and Space Research (IUCAF), began to set up proposals to increase radio astronomy allocations in the 71 – 275 GHz band. Initially, a strategy of obtaining allocations for a set of the most important spectral lines was considered, but was quickly discarded because of the difficulty in getting general agreement amongst astronomers. An alternative strategy was adopted. It was recognized that millimetre-wave telescope were already outfitted with receiving equipment that operated in the three atmospheric windows. However, these frequencies contained allocations to active services, including Earthward-transmitting satellite services. The strategy involved setting up proposals to move these allocations to the edges of the windows, without reducing their total bandwidths or subjecting the services to increased atmospheric attenuation. At the same time it is proposed to allocate as many of the frequency bands as possible covering the frequencies within the radio astronomy receivers to the radio astronomy service, passive services, or Earth-exploration satellite service (passive).

The WRC preparations extended over several meetings of the Working Party, together with inputs from an associated Working Party 7C which is concerned the Earth-exploration satellite service. The affected active services were consulted to ensure that they would not be disadvantaged by the moves. A final set of proposals was finalised during 1999, and this has been subsequently used as a basis for worldwide discussions. As a fitting conclusion to the considerable efforts of a relatively small number of people, similar final sets of proposals have now been endorsed by CITEL countries (the Americas and Canada), CEPT countries (Europe), and Asia-Pacific countries. Therefore, radio astronomers can feel rather confident of success at WRC-2000, which will guarantee excellent access to the high-frequency Universe for the foreseeable future. But that's not all! WRC-2000 will consider agenda items for the following WRC. One proposed item is the allocation of the radio spectrum above 275 GHz, currently not allocated. Because radio astronomy already operates extensively at these frequencies, it already has the information required to propose effective allocations.



are pinning their hopes on being to able to develop effective interference mitigation strategies as well as persuading governments to proclaim ‘radio-quiet’ reserves for the facilities.

References:

[1] Australian Communications Authority. *Australian Radiofrequency Spectrum Plan, January 1999.*

[2] ITU, Radiocommunication Bureau. *Handbook on Radio Astronomy*. Geneva, 1995.

[3] ITU, Radiocommunication Bureau. *ITU-R Recommendations, Radio Astronomy.* RA Series, Volume 1997, p.25.

[4] ITU, Radiocommunication Bureau. *ITU-R Recommendations, Radio Astronomy.* RA Series, Volume 1997, p.1.

Note added later

"At WRC-2000 ALL proposals were adopted."