# RECOMMENDATION ITU-R RA.479-5[*, **]

## Protection of frequencies for radioastronomical measurements in the shielded zone of the Moon

(1974-1978-1982-1990-1995-2003)

The ITU Radiocommunication Assembly,

*considering*

a) that Resolution B16 of the 1994 XXIIth General Assembly of the International Astronomical Union (IAU) (see Annex 2) recommends that, once radio astronomy observations in the Shielded Zone of the Moon (SZM) commence, radiocommunication transmissions in the SZM be limited to the 2-3 GHz band, but that an alternate band at least 1 GHz wide be identified for future operations on a time-coordinated basis between radio astronomy and lunar communication systems;

b) that radio astronomical discoveries resulting from observations from spacecraft above the atmosphere of the Earth will reveal unexpected new astronomical phenomena;

c) that, in addition to the establishment of line-of-sight communication links for scientific and other purposes between the Earth and spacecraft, it may be necessary to establish links between stations on the far side of the Moon and other stations on or visible from the Earth;

d) that Article 22, Nos. 22.22 to 22.25 of the Radio Regulations (RR) recognizes the necessity of maintaining the SZM as an area of great potential for observations by the radio astronomy service and by passive space research and consequently as free as possible from transmissions;

e) that earth satellites with high apogees, satellites in the halo orbits near the Sun-Earth $L_2$ point, satellites in the Earth-trailing orbits, deep-space probes and transmitters located near, or on the Moon may each illuminate the shielded zone, where the Sun-Earth $L_2$ Lagrange point is detailed in Recommendation ITU-R RA.1417,

*recommends*

**1** that, in planning the use of the radio spectrum, both nationally and internationally, account be taken of the need to provide for radio astronomy observations in the SZM;

**2** that, in taking account of such a need, special attention should be given to those frequency bands in which observations are difficult or impossible from the surface of the Earth;

**3** that the frequency spectrum should be used in the SZM in keeping with the preliminary guidelines contained in Annex 1;

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[*] This Recommendation should be brought to the attention of Radiocommunication Study Groups 1 and 3.

[**] Radiocommunication Study Group 7 made editorial amendments to this Recommendation in the year 2017 in accordance with Resolution ITU-R 1.

**4** that special attention be paid to emissions into the SZM from deep-space platforms, satellites in the halo orbits near the Sun-Earth $L_2$ point, satellites in the Earth-trailing orbits, or transmitters near or on the Moon;

**5** that in the frequency bands which would be considered for joint use by active and passive space stations in the SZM, radio astronomy observations should be protected from harmful interference. To this end appropriate discussions between concerned administrations may be conducted;

**6** that in-situ radiocommunication equipment developed for the environment of Mars or other planets should not be deployed in the SZM, but the choice of frequencies for the close proximity links in the SZM should follow the preliminary guidelines contained in Annex 1.

## Annex 1

## The protection of radio astronomy observations in the SZM

### 1 Introduction

The electromagnetic spectrum is now so heavily used on Earth that much of its potential value for passive scientific research has already been seriously affected. Because of the general increase in radiocommunications, especially involving earth satellites, spacecraft, and deep-space probes, it is important that frequency allocations by the International Telecommunication Union be coordinated to minimize interference with radio astronomy. In particular, since the far side of the Moon is the remaining accessible place where radio observations of the Universe are possible without interference over the whole radio spectrum, it is necessary to allocate frequencies for active use by deep-space probes, lunar satellites, scientific instrument packages and research stations on the lunar surface in such a way that interference with such passive observations is avoided.

Part of the Moon's surface is always protected from interfering signals generated on and near the Earth because the Moon always presents nearly the same side towards the Earth. It has a period of rotation about its axis equal to its period of revolution around the Earth, but because its orbit is slightly elliptical and inclined, observers on Earth can see somewhat more than half the surface of the Moon. If, in addition, the Moon is viewed from an earth satellite in an orbit of 100 000 km radius, another small fraction is seen. The remaining invisible portion of the Moon's surface is that which lies more than 23.2° beyond the mean limb of the Moon as seen from the centre of the Earth. The SZM consists of the shielded area of the Moon's surface together with an adjacent volume which is shielded from interference originating within a distance of 100 000 km from the centre of the Earth (Article 22, RR No. 22.22.1).

## 2 General preliminary guidelines for the use of the electromagnetic spectrum in the SZM

The SZM is expected to be free from terrestrial interference over the whole frequency spectrum. It is a unique site for scientific observations. As it is expected that radioastronomical and other scientific experiments will soon be carried out in this zone, it is essential to regulate the activities of the radio services whose facilities may illuminate it. Account must be taken of the requirements of earth satellites, deep-space probes and transmitters located in the SZM, on the understanding, however, that it is desirable to maintain the SZM as a zone free from radio interference and hence of great value for passive observations.

The use of the frequency spectrum by services with facilities which are located in the SZM or which illuminate it could be based on the following preliminary set of guidelines, which will need to be reviewed when additional information is received.

The entire radio-frequency spectrum in the SZM is designated as available for passive users (the radio astronomy service and other passive users as defined in the RR), with the following exceptions:

– frequency bands currently available and allocated in the future to the space research service, and those frequency bands in the space operation service, the Earth exploration-satellite service and the radiodetermination-satellite service, that are required to support space research;

– frequency bands currently available or allocated in the future for radiocommunication and for space research transmissions within the lunar shielded zone.

Except for these essential transmissions, it is intended to keep the SZM free from man-made transmissions. In the planning of such transmissions, it is desirable to avoid the areas of the spectrum of greatest astronomical importance and to provide frequency flexibility in transmitting systems.

The proposed guidelines do not impose any restriction on existing or future terrestrial radio services or on existing or future space radio services, the transmitters of which are switched on at a distance of less than 100 000 km from the centre of the Earth.

Under the proposed guidelines, existing or future space radio services for which transmitters are switched on at a distance of more than 100 000 km from the Earth and which operate in accordance with the RR should coordinate their activities with the radio astronomy service. It is essential that provisions governing compatibility between the radio astronomy service and other services, based on the technical features of the services, be specified by a decision adopted by the ITU.

## 3 Protection of radioastronomical observations in the SZM

For radioastronomical observations, the SZM presents unique advantages, which have been long recognized. In addition to offering the closest to an interference-free environment, advantages of the SZM for radio astronomy include the lack of a substantial atmosphere, which allows the study of regions of the electromagnetic spectrum which are inaccessible from the Earth. In particular, lack of a lunar ionosphere allows study of the spectra of celestial sources between about 50 kHz and

30 MHz. The absence of appreciable water vapour and oxygen in the lunar atmosphere allows observations of the microwave and submillimetre-wavelength region above about 50 GHz, which is either completely or partially absorbed by the atmosphere on Earth. Radio astronomers' interest in the SZM has been recognized in RR Article 22 (RR Nos. 22.22 to 22.25).

## 3.1 Lunar radio astronomy in the 30 kHz to 30 MHz range

Ionospheric limitations to ground-based radio astronomy below 30 MHz are described in Chapter 3 of the ITU Radioastronomy Handbook. Cosmic radio emission has been observed with ground-based radio telescopes at frequencies as low as 1.5 MHz, but observations below 30 MHz are possible only under exceptional circumstances, at special locations, and for limited periods of time. Terrestrial radio interference, natural as well as man-made, seriously limits the possibility of carrying out sensitive radio astronomy observations in this frequency range from near-Earth space as well as on the Earth. Radio interference in the 1-30 MHz range results largely from communications transmissions and noise which is generated in comparable amounts by human activity (ignition and machinery noise) and natural sources (mostly lightning). Below about 500 kHz, the dominant source of noise is auroral kilometric radiation (AKR), radio noise produced high above the auroral region. The entire frequency range below 30 MHz is either totally inaccessible or is extremely difficult to observe from the ground. Important scientific targets in this range include the galactic non-thermal background, the spectra of extra galactic sources, pulsars, interstellar refraction and scattering phenomena, and radio emission of the quiet and active Sun as well as Jupiter. Information about many of these cannot be obtained by any other means. Thus, the entire range below 30 MHz should be reserved for radio astronomy.

## 3.2 The 30-300 MHz range

This portion of the spectrum is heavily used by the active services on Earth to the point where it has become difficult to conduct radio astronomy observations. The region contains a number of weak, high-order radio recombination lines of carbon and nitrogen. Further, astronomers continue to search for the red shifted spectral line of neutral hydrogen (HI) in primordial galaxies, downwards in frequency to below 150 MHz. Continuum observations of pulsars, quasars, and steep spectrum sources are also of importance in this region of the spectrum. In the shielded zone, use of the range below 300 MHz by active services should be avoided entirely.

## 3.3 The 300 MHz to 3 GHz range

Some of the most interesting and heavily studied spectral lines lie in this portion of the spectrum, which also faces the heaviest competition and most commercial pressures at present. Lines of great astrophysical interest are:

– the 327.4 MHz hyperfine transition of the deuterium atom, an extremely weak line of great cosmological significance, detected in 1990 after many unsuccessful attempts;

– the 1 420.4 MHz neutral hydrogen (HI) line, discovered nearly four decades ago, and still the most intensely studied line in the radio spectrum;

– the four OH radical lines at 1 612.2 MHz, 1 665.4 MHz, 1 667.4 MHz, and 1 720.5 MHz.

Molecular radio astronomy began with the detection of the spectral lines of the OH radical in 1963. Several thousand spectral lines from more than 125 molecules have been discovered since then, and discovery of more lines continues to this day. The lines of greatest importance to radio astronomy are listed in Recommendation ITU-R RA.314. Nevertheless, important information has also been derived from many of those not listed as being of the greatest astrophysical significance.

Portions of the spectrum containing these lines and their limited blue- and red-shifted extensions are allocated to radio astronomy on Earth. Although heavily used, these bands have serious problems for astronomical observations either because they are not adequately protected from space-based in-band or out-of-band interference or because the band allocated to radio astronomy is far narrower than the red shift range of interest. For example, red shifted HI observations provide information on the formation of galaxies and the early Universe, topics that have been and continue to be the subject of intense research efforts. An example is the discovery of the 1 420.4 MHz line, red shifted to 323 MHz. The existence of red shifted OH megamasers, observable at frequencies as low as 500 MHz and below, has also been predicted. Highly red-shifted objects emitting in the HI or OH lines are expected to be of great interest to astronomers well into the next century. Since the Shielded Zone of the Moon is likely to be nearly interference free, interest in observations of these faint objects may increase greatly when a lunar observatory becomes available.

Continuum observations in the 300 MHz to 3 GHz range are carried out in the 1.4 GHz (1.400-1.427 GHz), 1.6 GHz (1.66-1.67 GHz), and 2.7 GHz (2.69-2.7 GHz) bands. The 2.29-2.3 GHz deep space band is also used to make very long baseline interferometry (VLBI) observations.

In view of the great astrophysical importance of red shifted HI and OH observations, the 300 MHz to 2 GHz range should be reserved for radio astronomy observations.

### 3.4 The 3-20 GHz range

This region of the spectrum is increasingly used by airborne or satellite services, and a number of astrophysically important lines have become difficult to observe. Some important lines were discovered only recently; e.g., the methanol line at 6.7 GHz, which is in the middle of bands allocated to satellite services.

Astrophysically important lines, most of which are not adequately protected and which have been detected in this spectral region are:

– methyladyne (CH) lines at 3 263.8 MHz; 3 335.5 MHz and 3 349.2 MHz, observed in our own, as well as in external galaxies;

– formaldehyde ($H_2CO$) lines at 4 829.7 MHz and 14.49 GHz also observed in our galaxy and external galaxies;

– methanol ($CH_3OH$) lines at 6.7 GHz and 12.2 GHz. These strong maser lines, discovered after 1987, have been observed in our Galaxy, as well as in the Magellanic Clouds, but have not been given recognition in the RR;

– cyclopropenylidene ($C_3H_2$) line at 18.3 GHz, observed in our Galaxy and in the Magellanic Clouds, but not recognized in the RR.

Continuum observations are also conducted in a number of bands in this spectral range with ground-based radio telescopes. The continuum bands used by radio astronomers are in the neighbourhood of the following bands allocated to the passive services: 4.99-5.0 GHz, 10.68-10.7 GHz and 15.35-15.4 GHz. Radio astronomers also make use of the 8.40-8.50 GHz deep-space band.

### 3.5 The 20-1 000 GHz range

Attenuation by neutral atmospheric gases becomes important in this range, as discussed in Chapter 3 of the ITU Handbook on Radioastronomy and Recommendation ITU-R P.676. Atmospheric water vapour attenuation begins to rise steeply above 10 GHz and becomes progressively stronger, peaking at 22.235 GHz. Strong lines of oxygen also attenuate emissions heavily in the vicinity of 60 GHz, 120 GHz and the water lines around 183 GHz. In the atmospheric windows between the absorption lines, astronomical observations become progressively more difficult as the frequency increases. This is because of increasing attenuation from the wings of the absorption lines, as well as increasing phase fluctuations, which make observations with high angular resolution difficult or impossible, even at high and dry sites. Thus, the lack of an atmosphere and extremely dry conditions make the far side of the Moon ideal for astronomical observations in this frequency range.

The astrophysically most important lines are listed in Recommendation ITU-R RA.314. Nevertheless, important information has also been derived from many of those not listed as being of the greatest astrophysical significance. The astronomical information derived from molecular line observations revolutionized our ideas about the dynamics and chemical composition of the interstellar medium as well as star formation and stellar evolution. In recent years the increased sensitivity of millimetre-wavelength telescopes and low-noise receivers has allowed the observation of many molecular lines in external galaxies, as well as our own, and contributed significantly to our understanding of Galactic structure and evolution. Far-infrared and molecular line emissions are strongly correlated, and recent far-infrared satellite data suggest the existence of large populations of molecular line emitting galaxies. Detections of the 115 GHz CO line, red shifted to frequencies as low as 36 GHz, suggests that molecular lines above 30 GHz may allow radio astronomers to explore important aspects of a large fraction of the Universe.

## 4 Conclusions

The prime consideration in the use of the shielded side of the Moon is the avoidance of radio interference generated on and near the Earth. The low frequency end of the spectrum, up to a few gigahertz, is the range in which radio astronomy suffers most severely from interference. As mentioned in § 3.3 above, the red shifting of the fundamentally important HI line of neutral hydrogen extends the range over which it can be observed from 1.42 GHz down at least as low as 323 MHz. In the 1-2 GHz range, there are the important OH spectral lines, some of which are in shared bands. Even in exclusively radio astronomy bands, observations suffer interference from out-of-band emissions in this range of rapidly expanding development. Observations below 300 MHz are also important and very difficult from most locations on Earth. *Thus, as a first requirement, all frequencies below 2 GHz in the SZM should be accessible to radio astronomy*. Alternate bands are necessary for those active transmissions absolutely indispensable for space operations, to enable total access.

In general, frequencies that would be most acceptable to radio astronomers for transmissions on the Moon are the higher ones; i.e., the range above 25 GHz. VLBI observations will produce very high data rates, the transmission of which to Earth does, in turn, require very wide bandwidths, possibly in excess of 2 GHz. These requirements may only be satisfied at frequencies above 25 GHz. It should be noted, however, that the number of molecular lines increases with frequency and, like the hydrogen line, many of these can be Doppler shifted over wide frequency ranges (e.g. the 115 GHz CO line). In addition, those spectral regions that cannot be observed from within the Earth's atmosphere because they coincide with the peaks of molecular absorption bands (e.g. the water vapour, or oxygen absorption lines) should be retained for radio astronomy observations. Some consideration must therefore be given to the choice of transmitting frequencies, as outlined below.

It is of great importance to provide adequate protection for the frequencies of the most important lines. In addition, the search for astrophysically important lines will continue, and bands containing interesting lines should be protected on the Moon. The potential for the discovery of such lines is indicated by the fact that the 6.7 GHz line of the methanol molecule, the second strongest maser ever detected, was discovered in 1991. Furthermore, it is highly desirable to protect somewhat greater bandwidths than is possible for allocations on the Earth. Systems developed and used for data transmission, or for other active purposes on the SZM should allow for enough frequency redundancy to ensure that, if a new discovery is made in a band used by them, operations may be vacated and moved to a different band to enable passive research.

Frequencies of continuum observations on the Moon will include those in the radio astronomy bands allocated on Earth, to allow direct comparison with terrestrial measurements and also to allow very long baseline interferometry with terrestrial stations. Thus, the existing primary and secondary radio astronomy allocations should be rigorously protected on the Moon. However, the bandwidths for many of these allocations are much smaller than are technically useful in modern receivers designed for maximum sensitivity, and it is important to avoid any such restriction on the Moon.

## Annex 2

## Resolution B16 concerning the bands to be used for radiocommunications in the lunar environment proposed by Commission 40 and 50

The XXIIth General Assembly of IAU,

*considering*

a) that radiocommunication systems between the Moon and the Earth, on the surface of the Moon, and in the surrounding environment of the Moon, are expected to be required in support of space research activities, including radioastronomy observations;

b) that some radiocommunication will be required in the shield zone of the Moon (SZM) as defined by RR Article 29, Sect. VI*;

c) that by the use of certain radio-frequency bands the requirements for such radiocommunication can be accommodated while at the same time providing the protection for radioastronomy intended by RR Article 29, Sect. VI*;

d) that in the SZM it is necessary to preserve as much of the spectrum as possible free of emissions;

e) that in assigning frequencies to the necessary transmissions it is important to avoid bands that:

– are of great astronomical importance;

– are difficult to observe from Earth because of interference or absorption in the atmosphere or ionosphere;

– that are important for interferometry between the Earth and the Moon;

f) that the bands mentioned in e) include:

– all frequencies below 2 GHz;

– frequencies of the most important spectral lines (IAU list) with bandwidth to cover essential red and blue shifts;

– radioastronomy allocations used on Earth for continuum observations with allowance for greater bandwidth to improve sensitivity,

*recommends*

**1** that two alternative bands must be allocated to the necessary active services in the SZM to retain access by the passive services to the whole spectrum on a time-coordinated basis;

**2** that radiocommunication in the shielded zone of the Moon be limited to the band 2 000-3 000 MHz;

**3** that the alternative frequency band at least 1 GHz wide be identified to permit future operations on a time coordinated basis between radioastronomy and lunar communication systems.

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* RR 1990 edition.