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| **Purpose/Objective:** Propose edits and updates to the Working document towards a preliminary draft new Report ITU-R RA.[NGSO-RAS-RQZ] |
| **Abstract:** The authors intend to provide edits and updates to Annex 1 of the latest 7D Report (7D/128), i.e. Working document towards a preliminary draft new Report ITU-R RA.[NGSO-RAS-RQZ]. The contribution will contain a description of the NRQZ boresight avoidance work as example in the Annex. |

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| **United states**Working Document towards a Preliminary Draft New Report ITU-R RA.[NGSO-RAS-RQZ] |
| Coexistence Measures between non-GSO satellite systems and RAS stations in the Radio Quiet Zones supporting the Square Kilometre Array (SKA) and the Atacama Large Millimeter/submillimeter Array (ALMA) |

The United States would like to provide an example of co-existence measures between Radio Quiet Zones and satellite operators and suggests to include that as an Annex to the main working document. The proposed new text is included in track changes.

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| Working Document towards a Preliminary Draft New Report ITU-R RA.[NGSO-RAS-RQZ] |
| Coexistence Measures between non-GSO satellite systems and RAS stations in the Radio Quiet Zones supporting the Square Kilometre Array (SKA) and the Atacama Large Millimeter/submillimeter Array (ALMA) |

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# 1 Introduction

Radio telescopes operating in remote areas have benefited for many years from broad access to the entire electromagnetic spectrum. Given the highly sensitive nature and weakness of the natural signals being detected, this has resulted in siting of RAS receivers by administrations in remote locations with extremely low population densities, as recommended by Recommendation [ITU-R RA.769-2](https://www.itu.int/rec/R-REC-RA.769/en) and more generally outlined in the Radio Regulations Article **29**. Additional protections from terrestrial receivers are provided through sovereign domestic regulations that in some cases establish special coordination or Radio Quiet Zones. For details on such zones refer to Report [ITU‑R RA.2259-1](https://www.itu.int/pub/R-REP-RA.2259). However, as Recommendation ITU-R RA.769-2 *recommends* 2 and 3 describe, as administrations seek to afford protection to particular radio astronomical observations, all practicable steps should be taken, including particularly from high altitude platform stations, spacecraft and balloons and when planning global systems.

This Report focuses specifically on studies called for in Resolution **681 (WRC-23)** *resolves* 5 of new coexistence measures between non-GSO satellite systems and RAS stations in the RQZs specified to be located around:

• The Square Kilometre Array Observatory (SKAO) in South Africa.

• The Atacama Large Millimeter/submillimeter Array (ALMA) in Chile.

The Report is laid out as follows: properties of the ALMA and South African Radio Quiet Zones in Sections 1.1 and 1.2, general and specific considerations for coexistence measures in Section 2, and a summary in Section 3.

[Editor’s Notes: This specifically lists the two RQZs called out under A.I. 1.16, and would be expected to provide additional technical information as it applies directly to the operating frequencies and geographic areas of these two RQZs, but will not repeat supplementary information already provided in RA.2259-1.]

## 1.1 Properties of the ALMA Protection and Coordination Zones

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), the U.S. National Science Foundation and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile. ALMA construction and operations are led by ESO on behalf of its Member States; by the NSF National Radio Astronomy Observatory (NRAO), managed by Associated Universities, Inc. (AUI), on behalf of North America; and the National Astronomical Observatory of Japan (NAOJ) on behalf of East Asia.

The ALMA radio telescope is situatedin an uninhabited region of northern Chile at an elevation of 5 000 m. To protect the operations of the ALMA telescope, the ALMA partners must abide by the regulations of the Chilean national telecommunications authority SUBTEL and the identical Resolution 1055 issued to AUI for North America and Resolution 1056 to the European Southern Observatory (ESO) in August 2004. The English-language translation of Resolution 1055 is presented in Attachment 1 to Annex 3 in Report ITU-R RA.2259-1.

In May 2003, AUI and ESO signed the acquisition from the Chilean Ministry of National Assets of land for the ALMA Operations Support Facility. In November 2003, the Chilean Ministry of National Assets provided a 50-year land concession for the construction and operation of ALMA on the Chajnator Altiplano, an area known as “the ALMA Concession.” In 2013, the land was designated for exclusive use of scientific activities and the National Commission for Research in Science and Technology (CONICYT) created the Parque Astronomico de Atacama (PAA) for managing the land concession. The PAA defined two zones centered on 23º 01’ S by 67º 45’ W:

i) Protection Zone: with a radius of 30 km, within Chilean national territory. Third-party transmitters operating within certain frequency bands may not be stationed within this zone.

ii) Coordination Zone: with a radius of 120 km, within Chilean national territory. Operators wishing to station certain kinds of transmitters within this zone are subject to a process whereby the opinion of the petitioners, ESO and AUI, are sought regarding requests that could interfere or affect the operation of the radio telescope.

Figure 1

ALMA protection and coordination zones, as defined by the SubTel Exempt Resolutions,
with a radius of 30 and 120 km respectively within the Chilean territory. The black line
shows the border between Chile, Bolivia, and Argentina



## 1.2 Properties of the South African Astronomy Advantage Area

[Describe South African Radio Quiet Zone details here that are pertinent from the Report ITU-R RA.2259 as well as telescope system characteristics relevant for this report.]

# 2 Considerations for coexistence measures between non-GSO satellite systems and RAS stations in specific RQZs

[Editor’s Notes: This specifically lists results from studies that directly apply to new coexistence measures between non-GSO and the two RAS facilities situated in the two RQZs to be studied]

## **2.1 General Considerations**

This analysis assumes the protection criteria as laid out in Recommendations ITU-R RA.769-2 and ITU-R RA.1513-2. Report ITU-R RA.2126 provides a summary of techniques that could be considered for mitigation of interference with radio astronomical observations. In the context of non-GSO satellite systems, the particular method of boresight avoidance is highlighted in Annex 1.

[Editor’s Notes: Provide more information on any general considerations here including approaches for coexistence of ground-based terminals and user terminals according to any national rules, and anything else that may be generally pertinent.]

## **2.2 Considerations specific to the Square Kilometre Array (SKA), South Africa**

## **2.3 Considerations specific to the Atacama Large Millimeter/submillimeter Array (ALMA), Chile**

A number of approaches could be taken to reduce or avoid potential corruption of astronomical data at the ALMA observatory.

### 2.3.1 Approaches for Coexistence between ALMA and Satellite System Operators

Given the operating frequencies of ALMA, satellites operating at altitudes of [typical altitudes], would be able to form small spot beams covering areas of [xxx-xxx km]. Approaches for coexistence between satellite operators and the observatory would allow for effective temporary boresight avoidance, while a particular observing band is in use. In addition, with sufficient separation, power levels from satellite systems could be minimized to be below thresholds specified in Recommendation ITU-R RA.769-1. Deployment of terminals and gateways are a matter of domestic regulation and are already covered under the protection zones specified and governed by licensing requirements through SUBTEL.

Possible approaches for coexistence that could be employed:

• Boresight Avoidance.

• Null Steering.

• Temporal Avoidance and Frequency Hopping.

• Reduction of transmit Power Levels.

# 3 Summary

# 4 Related ITU-R Recommendations/Reports

Recommendation ITU-R RA.769-2

Recommendation ITU-R RA.1513-2

Report ITU-R RA.2126

Report ITU-R RA.2259-1

# 5 Abbreviations/Glossary

**Annex 1**

**Example of operational co-existence measures – The National Radio Quiet Zone in the United States and boresight avoidance technique implemented by a Low Earth Orbit (LEO) satellite system**

The U.S. National Radio Astronomy Observatory (NRAO) and a LEO satellite operator have been engaged in coordinated testing efforts since Fall 2021, including conducting experiments on different interference avoidance schemes for the Karl G. Jansky Very Large Array (VLA) in New Mexico, and the Green Bank Telescope (GBT) inside the U.S. National Radio Quiet Zone in West Virginia. The satellite system used is capable of avoiding direct illumination of telescope sites with their adaptive tasking to place downlink beams far away. Nevertheless, even satellites operating in this mode can potentially present strong signals into the telescope’s receiver system if they pass close to the telescope’s main beam at the boresight. For additional protection, satellites can either momentarily redirect or completely disable their downlink channels while they pass within some minimum angular separation threshold from the telescope’s boresight, methods that are referred to as “telescope boresight avoidance.” In two separate experiments conducted since Fall 2023, NRAO and the satellite operator arranged to have the GBT observe a fixed Right Ascension/Declination position in the sky, chosen to have a large number of close-to-boresight Starlink passages. Preliminary analysis from these two experiments illustrates the feasibility of these avoidance methods to significantly reduce, if not eliminate, the negative impact of close-to-boresight satellite passages. Importantly, these experiments demonstrate the value of continuing cooperative efforts between NRAO and satellite operators, and expanding cooperation between the radio astronomy and satellite communities more generally.

Besides avoiding direct site illumination, the primary method to protect a telescope from satellite transmissions is through adaptive beam tasking that places a satellite’s downlink beams far away from the telescope site when the satellite is within a certain angular separation from the telescope’s boresight during observation. For example, a satellite that passes within 2 deg of boresight could be directed to steer its beams no closer than 180 km from a radio telescope. An additional protection level can be achieved by completely disabling downlink beams from satellites that pass within an even tighter cone of a telescope’s boresight during observation. This operational mode would further reduce the chance of a telescope's main beam being illuminated by any satellite’s downlink beam, including its inner sidelobes. At the moment, these two mitigation methods are referred to, both separately and collectively, as the “telescope boresight-avoidance” method. This experiment was made possible by sharing the radio telescope’s pointing position and frequency of observation with the LEO satellite operator, who was then able to use this data to mitigate interference in the telescope. The two experiments conducted at the GBT in 2023 October and 2024 February demonstrated:

1. When informed about a telescope’s pointing direction and the frequency band being observed, the satellite system is capable of disabling downlink beams for satellite passages close to telescope boresight. While this action is planned for the closest of boresight passages, it is expected that refraining from placing beams near the radio telescope will suffice for most near-boresight passages of consequence.
2. Briefly disabling satellite downlinks as a satellite passes close to boresight can significantly reduce the observed satellite emission in our data, indicated by statistically significant reductions in SNR by 2 orders of magnitude inside the 0°.5 radius.
3. For satellite passages using Channels 1 and 2, adjacent to a RAS primary allocation, although the SNR levels of the RA band between 10.68 and 10.7 GHz in both experiments are approximately unity, a closer inspection suggests a slight increase (about a factor of 3) in signal level in Experiment #1 for passages with Δθbs <= 0°. 5. This potential leakage is no longer an issue when boresight avoidance is in use for close passages.

The telescope boresight-avoidance method being developed by NRAO and a satellite operator is a novel way to ensure the coexistence of radio astronomy and commercial satellite operators in a way that mutually benefits the mission of both groups. The initial results from this work suggest that these avoidance methods, when properly implemented and tested, can simultaneously increase the range of communication services of a satellite operator while expanding the frequency bands on which a radio astronomy telescope can observe without harmful interference from the satellite constellation.