Australia's National
Science Agency

Observational Data Sharing (ODS) and General Satellite Interference Mitigation Documentation

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Contents

Executive Summary

This document provides detailed information on all the parameters provided by the ODS. Satellite operators should make use of these parameters to avoid boresight illumination of the telescopes, as well as to determine whether transmissions from satellites in the LIPD band are permitted or not. Any other future satellite interference mitigation methods are captured in this document as well.

Introduction

Within the Australian Radio Spectrum Plan (ARSP), there are specific radio astronomy (RAS) allocations covering parts of the spectrum that are of particular importance to astronomy, such as molecular line emissions. However, these allocations cover only a small part of the spectrum, whereas cosmic radio emissions of equal importance occur over the whole radio spectrum due to the laws of physics. Hence, to meet its science goals, radio astronomy facilities must operate in bands not specifically allocated to radio astronomy.

RAS receivers are many orders of magnitude more sensitive than receivers used in communications applications. To illustrate this, for the power spectral density of a typical mobile phone to be at the noise floor level of a RAS receiver, and in the absence of terrain shielding and clutter loss, the phone would need to be as far away as the outer solar system. Therefore, any signal emitted within the line of sight of a RAS facility, irrespective of distance for all practical purposes as far as satellite emissions are concerned, will be visible in the observed band of a RAS receiver. The receivers are in fact so sensitive, that even EMI from spacecraft electronics is readily visible – a new problem we are now facing with the unprecedented proliferation of LEO satellites, but so common now that we have coined a new term for this: Unintended electromagnetic radiation – UEMR.

In order to avoid emissions from transmitters in bands that are not specifically allocated to RAS, telescope facilities are built as far away from population centres as possible. This maximises terrain shielding and clutter loss for terrestrial transmitters and limits the amount of interference measured by radio astronomy observations. Transmissions from satellites therefore pose a particularly insidious problem to RAS.

In Australia there are many radio astronomy facilities. Observatories at a number of these facilities make passive observations in the frequency bands 50 – 350 MHz, 700 – 4032 MHz, 4.5 to 6.7 GHz, 8 to 12 GHz, 16 to 27 GHz, 30 to 50 GHz, and 75 to 116 GHz using receivers that are highly sensitive to interference. A detailed list of the facilities follows in chapter 1.

The Observational Data Sharing (ODS) system serves to provide status information on all Australian radio astronomy telescopes operating in the Radio Astronomy Service (RAS), allowing satellite operators to a) avoid site illumination, b) avoiding boresight illumination, and c) avoid transmitting in bands that are dynamically coordinated with RAS. All of these use cases are described in the following chapters.

1 Australian RAS Sites

The facilities in Australia are:

- the Australia Telescope National Facility (ATNF), operated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and comprising:
  - the Paul Wild Observatory, Narrabri (latitude 30° 18' 46.40" S, longitude 149° 33' 0.44" E), which operates in the bands 1.1 to 3.1 GHz, 3.9 to 12 GHz, 30 to 50 GHz and 75 to 115 GHz
  - the Parkes Observatory (latitude 32° 59' 54.25" S, longitude 148° 15' 48.65" E), which operates in the bands 432 to 448 MHz, 700 to 4032 MHz, 5.9 to 7 GHz, 8 to 9 GHz, and 16 to 26 GHz
  - the Mopra Observatory, Coonabarabran (latitude 31° 16' 04.12" S, longitude 149° 05' 58.72" E), which operates in the bands 1.3 to 3 GHz, 4.5 to 6.7 GHz, 8 to 9.2 GHz, 16 to 27 GHz, 30 to 50 GHz, and 76 to 116 GHz
  - ASKAP (latitude 26° 41' 49.20" S, longitude 116° 37' 53.13" E) uses state-of-the-art Phased Array Feeds (PAF) to survey a large area of the sky. It operates in the frequency band 700 to 1800 MHz.
- the Mount Pleasant Observatory (latitude 42° 48' 12.92" S, longitude 147° 26' 25.86" E), operated by the University of Tasmania, which operates in the bands 1.1 to 3.1 GHz, 2.2 to 2.6 GHz, 4.6 to 5 GHz, 8.2 to 8.7 GHz, 12 to 12.4 GHz, and 19.8 to 20.2 GHz
- the Ceduna Observatory (latitude 31° 52' 03.69" S, longitude 133° 48' 35.40" E), operated by the University of Tasmania, which operates in the bands 1.2 to 1.8 GHz, 2.2 to 2.6 GHz, 4.6 to 5 GHz, 8.2 to 8.7 GHz, 12 to 12.4 GHz, and 19.8 to 20.2 GHz
- the Canberra Deep Space Communication Complex (latitude 35° 23' 54.46" S, longitude 148° 58' 39.66" E), which is also used for radio astronomy observations in the bands 1.4 to 1.9 GHz, 2.2 to 2.3 GHz, 8.2 to 8.6 GHz, 17 to 27 GHz and 31.8 to 32.3 GHz
- the Molonglo Observatory Synthesis Telescope (MOST) near Canberra (latitude 35° 22' 14.6" S, longitude 149° 25' 28.9" E), operated by the University of Sydney, which observes in the frequency range 840 to 845 MHz
- the AuScope network operated by the University of Tasmania, which observes in the space research service bands at 2.3 GHz and 8.4 GHz as well as opportunistically using broadband receivers from 2 to 14 GHz. It is used by the International VLBI Service (IVS) for geodetic and astrometric VLBI observations. The antennas are located at Hobart (latitude 42° 48' 20.06" S, longitude 147° 26' 17.31" E), Yarragadee (latitude 29° 02' 49.72" S, longitude 115° 20' 44.26" E) and Katherine (latitude 14° 22' 31.67" S, longitude 132° 09' 08.54" E). These antennas also join the Australian LBA for astronomy VLBI observations.
- The Square Kilometre Array Observatory (SKAO) operates operates over the frequency range of 50 MHz to 25.25 GHz (the core is located at latitude 26° 49' 29.0" S, longitude 116° 45' 52.0" E) within the bounds of Inyarrimanha Ilgari Bundara, our Murchison Radioastronomy Observatory (latitude 26° 42' 10.4" S, longitude 116° 39' 37.0" E)
- The Murchison Widefield Array (MWA) (latitude 26° 42' 11.95" S, longitude 116° 40' 14.94" E) is operated by a consortium of research institutes. Its antennas are optimised for the 80 to 300 MHz frequency range and is located within the bounds of Inyarrimanha Ilgari Bundara, our Murchison Radioastronomy Observatory (latitude 26° 42' 10.4" S, longitude 116° 39' 37.0" E)
- The Experiment to Detect the Global Epoch of Reionization Signature (EDGES) (latitude 26° 42' 53.49" S, longitude 116° 36' 12.52" E) is operated by a consortium of research institutes and operates from 50 to 100 MHz and is located within the bounds of Inyarrimanha Ilgari Bundara, our Murchison Radioastronomy Observatory (latitude 26° 42' 10.4" S, longitude 116°

39' 37.0" E)

- the Learmonth Solar Observatory (LSO) operated by the Bureau of Meteorology (latitude 22° 13’ 9” S, longitude 114° 6’ 11” E) conducts passive observations above the sun's background level in the frequency bands 232-257 MHz, 389-441 MHz, 602-618 MHz, 1407-1423 MHz, 2681-2708 MHz, 4900-5100 MHz, 8700-8900 MHz and 15300-15500 MHz, using receivers that are highly sensitive to interference.

Note: All geographic coordinates in this document are given using the Geocentric Datum of Australia 1994 (GDA94).

2 Mitigation instructions for satellite operators

The ODS updates every 30 seconds, on the 00 and 30 second marks. If your system is set up to ingest ODS data a few seconds after these times, you will have the most current and up to date information.

2.1 Avoiding site illumination

As a rule, satellite operators capable of steering their ground beams are requested to not place any footprints at the exact locations of the RAS sites. This may help mitigate their impact on RAS observations by avoiding scattering of the strongest signals off elements of the telescope structures and entering the RF path to the RAS receivers. Most RAS sites are located some distance away from where service area footprints are desirable, and if there is a need to serve an area in the immediate neighbourhood of a site, judicious placement of footprints should be employed and at the very minimum boresight avoidance should be used.

2.2 Boresight illumination avoidance

Of particular concern is beam coupling: when the telescope beam aligns with the transmitted beams from the satellites, extremely strong signals are observed in the RAS receivers, amplified by the full gain of the telescopes, between 55 and 88 dB, depending on site and frequency. This generally leads to the complete loss of the entire bandpass in the RAS receiver (including frequencies inside RAS protected bands) due to both frontend low noise amplifiers (LNAs) being overpowered and becoming non-linear in their response, and elements of the RAS receiver backend such as down-converted intermediate frequencies, filter banks, and samplers being unable to cope with signals of that magnitude. Modern day RAS receivers have observing bandwidths of several GHz and are thus unable to avoid overlapping with active frequencies. While some mitigation measures are undertaken at the RAS receiver end by ensuring new receiver systems have a much higher dynamic range, mitigating this completely for existing receiver systems is neither affordable or practical, nor can current generation RF filters be used as they introduce significant loss of signal, leading to an unacceptable performance degradation of the RAS receiver systems.

Considering that it takes a satellite operator some time to propagate the telescope pointings to their satellite constellation to avoid boresight illumination, much effort is taken on the RAS side to provide timely updates of where the telescopes are pointing at present and up to 30 minutes into the future. It is however not always possible to provide all of that information, which is why two levels of pointing information are provided: Current position, and the future track.

Therefore, in order to implement boresight avoidance, satellite operators should use the following procedure to derive the best possible information from each site listed in the ODS:

1. Take note of the data_valid parameter for the site. If this is false, there is a communication issue between the ODS and the site monitoring equipment. There is nothing further to be done for you, and no further information should be consumed or acted on. But please continue to not place footprints on the site if that is what you are already doing.

2. Take note of the site_active parameter. If this is false, the telescope is currently not in use, and no further mitigation measures must be taken. But please continue to not place footprints on the site and use boresight avoidance for the current telescope pointing position, as engineering and testing work may be going on.
3. Take note of the tracking_mode parameter, which can either be azel or radec. Most commonly, radec (Right ascension and Declination) will be used, but occasionally the telescope facilities are also tracking other objects such as artificial satellites, deep space satellites, comets, or other solar system bodies that are not adequately described by an RA/Dec trajectory.
4. Check if there is data in the future_track point. If there is data, this describes the anticipated future track of the telescope up to 30 minutes into the future. The coordinates used in that list correspond to the tracking_mode parameter: if it's radec, the coordinates are in right ascension (degrees), declination (degrees) and their respective rates between the timestamps. If it's azel, the coordinates are in azimuth (degrees) and elevation (degrees), as are their corresponding tracking rates.
5. If there is no data in the future_track point, depending on which tracking_mode is in use, consult either the rightAscension/declination points or Az/El points, along with the corresponding trk_rate_[ra/az/dec/el]_deg_per_sec points to obtain the tracking rate in the coordinate system given by tracking_mode. You will have to calculate the future point of where the telescope will be pointing at the times that are useful for ingestion into your boresight avoidance system yourself.

2.3 LIPD 915 – 928 MHz transmissions

To determine transmission eligibility at the ARQZWA site susceptible to interference in the low interference potential devices (LIPD) band, the following procedures should be adhered to:

1. Note this limitation is only applicable to the ARQZWA site. This corresponds with the ASKAP telescope entry in the ODS. The other sites are exempted from this limitation.
2. If transmissions are not permitted, your satellites must cease transmission prior to the calculated emissions at the site exceeding the PSD threshold of -234 dBm/Hz.

   The power spectral density (PSD) of your emissions should be calculated at the site using the propagation models as described in Recommendation ITU-R P.619-5. LIPD transmission should cease when calculated emission at the site is above -234 dBm/Hz.
3. Check the ASKAP site's data_valid tag. If data_valid is false, it should be assumed that transmissions are **not** permitted and you can stop the processing logic here.

   This flag only goes to false when a communication problem between ODS and the site infrastructure is occurring, preventing the actual telescope state from being obtained. Given the nature of the RAS observation campaigns at the sites, it is likely that observations in the LIPD band are ongoing, hence defaulting to transmission not permitted.

4. Check the LIPD_tx_allowed tag. If this is true, transmissions are permitted. If false, transmission are not permitted. This flag will switch to true during the LIPD_next_txwindow_start and LIPD_next_txwindow_end times.
5. The LIPD_next_txwindow_start and LIPD_next_txwindow_end times (in UTC) should be used by the satellite operator to schedule transmitters to be switched on or off.
6. The LIPD_next_txwindow_start and LIPD_next_txwindow_end times are only filled if observations presently are taking place in the affected frequency band. A time window of 5% of observing time is provided to operators during which time, even if RAS observations are in progress, transmissions are permitted. During multi day observations spanning the LIPD 915 – 928 MHz band, after 2880 minutes, a window of 144 minutes is scheduled for this purpose.

3 JSON Format Documentation

3.1 Overview

The status of the CSIRO ODS system can be viewed on the URL https://www.narrabri.atnf.csiro.au/ods/

JSON data consumers should access the JSON file directly via the URL https://www.narrabri.atnf.csiro.au/ods/ods.json

The JSON file contains a list of all sites presently participating in the ODS. The key to each site is the name of the site. Over time, more sites may be added to this, so it is important that your code iterates through all top-level objects to obtain the full list of sites.

The only special key in the top level is the ODS key, it provides information about the status of the ODS system itself, currently limited to the "updated" timestamp.

The first element to check then is the "ODS"->"updated" timestamp, in UTC. This should be no older than 60 seconds to consider the ODS data to be current. The ODS system updates data every 30 seconds.

3.2 Adding facilities

Facilities wishing to have their data included in the ODS will need to provide a JSON format file for ingest by the ODS that implements the data points listed in section **3.3 Telescope data points** below. Note that any points referring to LIPD are Australia specific. If your national administration regulates other spectrum for use from space or other itinerant transmitters such as airborne transmitters, you may include these fields for the consumers of this data.

The data should be updated every 30 seconds.

An example of the full JSON file you should make available is printed here for your convenience:

```
{
    "site_lat_deg": -31.27,
    "site_lon_deg": 149.1,
    "site_el_m": 822,
    "site_id": "mopra",
    "updated": "2025-05-15 22:44:31",
    "site_active": true,
    "data_valid": true,
    "Az": 138.75122222222222,
    "El": 47.47372222222222,
    "src_id": "static tracking test",
    "rightAscension": 54.5275,
    "declination": -54.88827777777778,
    "freq_lower_hz": 1142000000,
    "freq_upper_hz": 3004000000,
    "src_radius": 0.341841318525175,
    "corr_integ_time": 2,
    "src_is_pulsar_bool": false,
    "notes": "",
    "trk_rate_ra_deg_per_sec": 0,
    "trk_rate_dec_deg_per_sec": 0,
    "trk_rate_az_deg_per_sec": 0,
    "trk_rate_el_deg_per_sec": 0,
    "tracking_mode": "azel",
    "future_track": [
      [
        "2025-05-15 22:44:31",
        "2025-05-15 22:45:31",
        138.75122222222222,
        47.47372222222222,
        0,
        0,
        1142000000,
        3004000000,
        false
      ],
      [
        "2025-05-15 23:12:31",
        "2025-05-15 23:13:31",
        138.75122222222222,
        47.47372222222222,
        0,
        0,
        1142000000,
        3004000000,
        false
      ]
    ]
  }
```

Once your data is ready for ingest, please contact us with instructions on where to access the data from.

3.3 Telescope site data points

Following is a list of every data point that may be encountered in each site.

3.3.1 updated

Data type: String

Values: True/False

This point contains the timestamp of when the site data was last updated in UTC and in format "%Y-%m-%d %H %M %S".

Example: "updated": "2025-01-24 23:27:37"

3.3.2 data_valid

Data type: Boolean

Values: True/False

This indicates whether the site data is valid or not. If an internal processing error has occurred, or if data cannot currently be obtained from the telescope site, this will be set to false.

3.3.3 tracking_mode

Data type: String

Values: radec/azel

This indicates whether the telescope is tracking a source in azimuth/elevation coordinates, or in RA/Dec coordinates. This determines which tracking rate you should consult to project future positions for the telescope

3.3.4 trk_rate_az_deg_per_sec

Data type: Float

This contains the tracking rate of the telescope in azimuth in degrees per second. Satellite operators should use this to calculate the future position of the telescope if tracking_mode == azel, and if future_track information is empty.

3.3.5 trk_rate_el_deg_per_sec

Data type: Float

This contains the tracking rate of the telescope in elevation in degrees per second. Satellite operators should use this to calculate the future position of the telescope if tracking_mode == azel, and if future_track information is empty.

3.3.6 trk_rate_ra_deg_per_sec

Data type: Float

This contains the tracking rate of the telescope in J2000 RA in degrees per second. Satellite operators should use this to calculate the future position of the telescope if tracking_mode == radec, and if future_track information is empty.

3.3.7 trk_rate_dec_deg_per_sec

Data type: Float

This contains the tracking rate of the telescope in J2000 declination degrees per second. Satellite operators should use this to calculate the future position of the telescope if tracking_mode == radec, and if future_track information is empty.

3.3.8 future_track

Data type: List of lists

Values: List of lists, each with elements of type String and Float

This contains a list of the future positions of the telescope either in J2000 RA/dec position pairs and RA/dec tracking speed pairs, or in Az/El position pairs and Az/El tracking speed pairs, depending on the tracking_mode. The elements in the list contain the start timestamp, end timestamp, position at the start, as well as lower and upper frequency in use and whether pulsar observations are being executed. The tracking speed is in degrees per second.

Example: [["2025-02-03 06:03:30", "2025-02-03 06:33:30", 333.59577777777776, -27.531266666666667, 0, 0, 1092500000, 1452500000, false]]

3.3.9 site_lat

Data type: Float

The geographical latitude of the site in degrees

3.3.10 site_lon

Data type: Float

The geographical longitude of the site in degrees. Note that by convention, eastern longitudes are positive, western longitudes negative.

3.3.11 site_el_m

Data type: Float

The site elevation in meters.

3.3.12 site_id

Data type: String

The site identification.

3.3.13 corr_integ_time_sec

Data type: Float

The correlator integration time in seconds.

3.3.14 src_id

Data type: String

The name of the source being observed.

3.3.15 src_ra_j2000_deg

Data type: Float

The J2000 RA of the source being observed in degrees.

3.3.16 src_dec_j2000_deg

Data type: Float

The J2000 declination of the source being observed in degrees.

3.3.17 src_is_pulsar_bool

Data type: Boolean

Indicates True if the source being observed is a pulsar.

3.3.18 slew_sec

Data type: Float

The number of seconds spent to slew to the source

3.3.19 src_start_utc

Data type: String

The timestamp in UTC when the observation is starting.

Example: "2025-01-24T20:47:09.000000"

3.3.20 src_end_utc

Data type: String

The timestamp in UTC when the observation is ending.

Example: "2025-01-25T06:47:09.000000"

3.3.21 notes

Data type: String

Any pertinent notes to this observation.

3.3.22 site_active

Data type: Boolean

True if the facility is currently observing.

3.3.23 freq_lower_hz

Data type: Float

The lower end of the frequency band being observed in Hz.

3.3.24 freq_upper_hz

Data type: Float

The upper end of the frequency band being observed in Hz.

3.3.25 src_radius

Data type: Float

The angle on the sky being observed at present in degrees. Set this to the largest diameter being observed. When using a multibeam receiver for instance, make sure this radius encompasses the entire field being observed. If only a single beam but multiple frequencies are observed, set this to the largest beam diameter (at the lowest frequency).

3.3.26 LIPD_tx_allowed

Data type: Boolean

Indicates whether transmissions from satellites in the LIPD band (915 – 928 MHz) are presently allowed or not. True if allowed, False if not allowed.

Please note that when these transmissions are not permitted, an exclusion horizon over the entire radio horizon across the provided site latitude and longitude must be factored in.

3.3.27 LIPD_next_txwindow_start

Data type: String

The UTC timestamp from which LIPD band transmissions from satellites will be permitted. This is scheduled to not surpass more than 5% of the time and, if continuous observations are made in the affected band, will switch every 2880 minutes after commencement of the observations to allow for 144 minutes of transmission.

Note this is only present for sites where receivers operate in the LIPD band (currently ASKAP and Parkes).

3.3.28 LIPD_next_txwindow_end

Data type: String

The UTC timestamp from which LIPD band transmissions from satellites must cease. Calculated based on the amount of time that has elapsed since observations in the band have commenced.

Note this is only present for sites where receivers operate in the LIPD band (currently ASKAP and Parkes).

References

The CSIRO ODS system was developed by Balthasar Indermuehle and Jamie Stevens (both CSIRO) and with the participation of the University of Tasmania for the Hobart, Ceduna, Yarragadee, and Katherine facilities.

The National Radio Astronomy Observatory (NRAO) develops and maintains the NRAO format JSON standard upon which the NRAO JSON format output of the CSIRO ODS system is based.

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