Coordination Agreement between
the European Space Agency (ESA)
and
the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF)

on the mutual planning procedure for EESS (active) cloud profile radar operations with radio astronomy service observations in the band 94-94.1 GHz
between EARTHCARE[*] and IUCAF

version 2, January 2022

1. Introduction

This Coordination Agreement is a result of the discussions between representatives of the European Space Agency (ESA) and the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF). The satellite sensor and radio astronomy service (RAS) observatories addressed in this Coordination Agreement are listed in Tables 1 and 2.

2. Systems addressed in this agreement

2.1 Satellite sensor

This coordination considers the use of the 94 – 94.1 GHz band (space-to-Earth) by the CPR (Cloud Profiling Radar) onboard the EARTHCARE (Earth clouds, aerosols and radiation explorer) satellite. The characteristics of the EARTHCARE CPR are included in Table 1.

Satellite sensor	Orbital Position	Frequency	Bandwidth	Status
EARTHCARE (API/A/12112)	NGSO	94.05 GHz	7 MHz	Planned (March 2023)

Table 1 - ESA's satellite sensor

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[*] The mission is also known as EarthCARE

2.2 Radio astronomy stations

The list of radio astronomy observatories in the band 94-94.1 GHz is provided in Table 2.

Radio observatory	Center of the observatory	Size of array telescopes
Metsähovi, Finland	E 24°23'17" N 60°13'04"	N/A
Onsala, Sweden	E 11°55'35" N 57°23'45"	N/A
Pico Veleta, Spain	E -03°23'34" N 37°03'58"	N/A
Plateau de Bure, France	E 05°54'26" N 44°38'01"	5 km radius
Sardinia Radio Telescope, Italy	E 09°14'40" N 39°29'50"	N/A
Yebes, Spain	E -03°05'22" N 40°31'27"	N/A
ALMA, Chile	E -67°45' N -23°02'	15 km radius
LMT, Sierra Negra, Mexico	E -97°18'53" N 18°59'06"	N/A
Green Bank, WVa, USA	E -79°50'23" N 38°25'59"	N/A
Haystack, MA, USA	E -71°29'18" N 42°37'24"	N/A
Simons Observatory, USA	E -67°47′15″ N -22°57′31″	N/A
Owens Valley, CA, USA	E -118°16'56" N 37°14'03"	N/A
Steward, AZ, USA	E -111°36'53" N 31°57'12"	N/A
Brewster, WA, USA	E -119°41'00" N48°07'52"	N/A
Fort Davis, TX, USA	E -103°56'41" N30°38'06"	N/A
South Pole Telescope, Keck/Bicep Experiment USA	N -90°	N/A
Kitt Peak, AZ, USA	E -111°36'45" N31°57'23"	N/A
Los Alamos, NM, USA	E -106°14'44" N 35°46'30"	N/A
Mauna Kea, HI, USA	E -155°27' 20" N 19° 48' 05"	N/A
North Liberty, IA, USA	E -91°34'27" N 41°46'17"	N/A
Pie Town, NM, USA	E -108°07'09" N 34°18'04"	N/A
ATCA, Australia	E 149°32'56" N -30°18'52"	5 km radius
Tamna, Korea	E 126º27'43" N 33º17'18"	N/A
Ulsan, Korea	E 129º15'04" N 35º32'33"	N/A
Yonsei, Korea	E 126º56'35" N 37º33'44"	N/A
MOPRA, Australia	E 149º05'58" N –31º16'04"	N/A
Nobeyama, Japan	E 138°28'32" N 35°56'29"	N/A
Purple Mountain, China	E 118°47'48.8" N 32°03'57.2	N/A
Seoul, Korea	E 126º57'19" N 37º27'15"	N/A
Taejon, Korea	E 127°22'18" N 36°23'54"	N/A

Table 2 – RAS observatories in the 94-94.1 GHz band

3. Technical Discussions / General Statements

The aim of this operational coordination agreement is to avoid transmissions through the main beam of the EARTHCARE CPR directly at stations of the RAS, in accordance with ITU-R Radio Regulations No. 5.562A (see Annex 1), Recommendation ITU-R RA.1750-0 (see Annex 2) and Resolution SFCG 24-2 (see Annex 3).

In 2019, ESA in collaboration with JAXA, developed a technical note [1] on the subject of setting the EARTHCARE CPR to "Silent State" mode to avoid direct illumination of RAS sites. In this technical note, the CPR is assumed to be pointing towards nadir, the RAS main lobe is assumed to be pointing towards the CPR, and all uncertainties in the attitude and orbital position of the spacecraft, in the planning/execution of on-board operations plus some margins vis-à-vis the RAS location zone are altogether taken into account to derive the so-called 'worst case'.

This note concluded that, to avoid direct illumination of RAS sites, the CPR has to be set to "Silent State" for approximately 3.5 seconds (worst case) when passing over RAS sites. Due to the instrument instability following exit from "Silent State", 5 minutes of data will be flagged as "uncertain data quality" after each time the "Silent State" is set. In an orbital cycle (25 days), this results in a total of 2' 42" of "Silent State" (worst case) and a total of 3h 52' 42" of data flagged as "uncertain data quality".

The baseline operations plan of the EARTHCARE CPR includes setting the CPR to "Silent State" when over the RAS site (with the margins described in the technical note), thus avoiding the risk of main beam to main beam coupling which may damage the receivers of the RAS stations. The estimated power flux density on ground during normal operations as well as the information necessary to compute the power flux density in a generic direction are included in Annex 4.

In parallel, ESA will also establish and maintain a dedicated webpage to report the list of all events where the CPR is scheduled to become in direct visibility of a RAS site; that webpage information will be refreshed on a weekly basis.

The reference orbit of Table 3 is targeted for all EARTHCARE in-orbit routine operations and will be maintained into a ±25 km dead-band corridor (i.e. there is a ±25 km uncertainty in the longitude of the satellite); the longitude of the descending node will be frozen at a later stage prior launch.

Parameter	***Mean Kepler***
Semi-major axis	*a = 6771.28 km*
Eccentricity	*e = 0.001283*
Inclination (sun-synchronous)	*i = 97.050°*
Argument of perigee	*ω = 90°*
Mean Local Solar Time, Descending Node	*MLST = 14:00 DN*
Repeat cycle / cycle length	*25 days, 389 orbits*
Orbital duration	*5552.7 s*
Mean Spherical Altitude	*393.14 km*
Minimum Geodetic Altitude	*398.4 km*
Maximum Geodetic Altitude	*426.0 km*
Average Geodetic Altitude	*408.3 km*

Table 3 – EARTHCARE reference orbit

4. Agreed coordination procedure

The following mutual planning procedure has been agreed:

1. The EARTHCARE CPR will be set to "Silent State" when above the RAS sites included in Table 2 and with the margins specified in [1]. In parallel, ESA will maintain a webpage with information of predicted fly-overs; the periodicity for refreshing that information will be driven by mission planning activities so nominally once per week.

2. ESA, as space agency responsible for the operation of the EARTHCARE CPR, shall provide all relevant information via the SFCG Website (http://www.sfcgonline.org) at least 6 months before the launch (TBC) of the satellite. This information will include all the orbital elements that are necessary to allow the avoidance of radio astronomy observations during line-of-sight transmissions from the EARTHCARE CPR sensor and the identification of the designated contact persons.

3. Before launch or during any time of the operation of the EARTHCARE, if there is any change in the planned operation of the EARTHCARE CPR (in terms of time and duration of operation and area of operation), ESA shall provide this information immediately by updating the SFCG Website and by informing IUCAF point of contact (PoC) via email.

4. IUCAF will inform the radio observatories that are potentially concerned of planned EESS (active) missions and provide them with instructions on the use of the information available on the SFCG Website that will allow the planning of observations avoiding line-of-sight transmissions from the EESS (active) sensor. In case of new RAS observatories, IUCAF will provide the necessary information with a 6-month advance notice to ESA in order to provide sufficient time to modify planning rules of CPR in-orbit operations and validate them accordingly. IUCAF will also group information about new RAS sites in such a way that ESA will not need to amend CPR operational planning more than twice per year.

5. During any stage of this mutual planning procedure, ESA and IUCAF shall ensure the availability of their designated PoCs.

The primary and backup contact points of the coordination activity shall be as follows:

EARTHCARE and IUCAF Operational Coordination Agreement

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E-mail communications should also be copied to iucafchair@iucaf.org, to ensure the shortest reaction time.

5. Conclusions

ESA and IUCAF acknowledged that transmissions from the EARTHCARE CPR that are directed into the main beam of a radio astronomy antenna have the potential to damage the receivers of RAS observatories. Therefore, ESA and IUCAF agreed that operational coordination is needed.

ESA agreed to provide the orbital information for the EARTHCARE spacecraft before launch, and to provide updated orbital scenario information, as needed, after launch.

ESA agreed to set the EARTHCARE CPR in “Silent State” when above the RAS sites included in Table 2 and with the margins specified in [1]. In parallel, ESA will maintain a webpage with RAS fly-over prediction; this information will be nominally refreshed on a weekly basis.

ESA and IUCAF agreed to assure availability of their contact persons identified in Section 4 and when necessary to communicate any change in the list of contact persons.

IUCAF agreed to interface with the RAS observatories, as needed, to provide them with relevant information about the EARTHCARE CPR. IUCAF also agreed to update Table 2 on the basis established in Section 4.

Based on the discussion in Sections 3 and 4 above, ESA and IUCAF agreed that coordination for use of the 94-94.1 GHz band between the EARTHCARE CPR and the RAS observatories is complete.

6. References

[1] ESA/ESRIN Technical note “EARTHCARE CPR Silent State Management over RAS Sites”, EACA-GSEG-EOPG-IC-16-0014

[2] Recommendation ITU-R RA.1750-0 “Mutual planning between the Earth exploration-satellite service (active) and the radio astronomy service in the 94 GHz and 130 GHz bands”

[3] Recommendation ITU-R RS.1166-4 “Performance and interference criteria* for active spaceborne sensors”

[4] Recommendation ITU-R RS.2105-0 “Typical technical and operational characteristics of Earth exploration-satellite service (active) systems using allocations between 432 MHz and 238 GHz”

[5] Report ITU-R RA.2188-0 “Power flux-density and e.i.r.p. levels potentially damaging to radio astronomy receivers”

[6] Resolution SFCG 24-2 “Use of the allocation for EESS (active) in the band 94-94.1 GHz”

[7] Report SFCG 39-2 “Max PFD Levels from EESS active and Burnout Levels of RAS Systems”.

EARTHCARE and IUCAF Operational Coordination Agreement

For ESA	**For IUCAF**
Mr. Enrico Vassallo **Head, Frequency Management Office**	**Mr. Harvey S. Liszt** **Chair, IUCAF**
Dated:	**Dated:**

Annex 1

Frequency allocations near 94 GHz

92-94	FIXED 5.338A MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149
94-94.1	EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION SPACE RESEARCH (active) Radio astronomy 5.562 5.562A
94.1-95	FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149

5.562 The use of the band 94-94.1 GHz by the Earth exploration-satellite (active) and space research (active) services is limited to spaceborne cloud radars. (WRC-97)

5.562A In the bands 94-94.1 GHz and 130-134 GHz, transmissions from space stations of the Earth exploration-satellite service (active) that are directed into the main beam of a radio astronomy antenna have the potential to damage some radio astronomy receivers. Space agencies operating the transmitters and the radio astronomy stations concerned should mutually plan their operations so as to avoid such occurrences to the maximum extent possible. (WRC-2000)

Annex 2

Excerpt from Recommendation ITU-R RA.1750-0 “Mutual planning between the Earth exploration-satellite service (active) and the radio astronomy service in the 94 GHz and 130 GHz band”

recommends

1. that as early as possible in the design cycle of such an EESS (active) cloud radar system, contact should be established between the EESS (active) designers and operators and with radioastronomy sites – the international organization IUCAF may provide the initial link between the EESS operators and potentially affected radio astronomy observatories;
2. that close contact between radio astronomers and the operators of the EESS (active) system should be maintained throughout the design and operational life-cycles of all systems which are subject to sharing in the 94 GHz and 130 GHz bands such that each party is apprised of pertinent developments within the other;
3. that the design and operation of systems operating in each service should be performed so as to account for sharing to the greatest practicable extent;
4. that the considerations relevant to sharing given in Annex 1 should be taken into account in the design and operations of such systems;
5. that the example provided in Annex 2 of the impact upon one instrument operating in the radio astronomy service from one satellite operating in the EESS (active) should be taken into account in the design and operation of stations of both services.

Annex 1: Considerations relevant to the design and operation of systems intended for sharing between EESS (active) and RAS

For the EESS (active):

- An active radar system should be designed according to best engineering practices to minimize unwanted emissions, and to minimise off-axis emission from the radar antenna into sidelobes.
- So far as is practicable, an EESS (active) system should be designed and operated in such a way as to avoid transmitting through its main beam directly at stations of the RAS.
- Operators of an EESS (active) system should ensure that all operational help possible be given to RAS stations, such as providing timely orbital details of the satellite radar.

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For the RAS:

- RAS stations should be designed to be able to prevent their antennas from pointing directly at the orbiting radar, by flexible dynamic scheduling of observations or other means.
- RAS stations should provide the means to protect their receivers from physical damage if complete avoidance of main beam encounters is impracticable.
- To the extent reasonably possible, without compromising the capability of the RAS station, RAS receiver systems should be designed to have a high tolerance for damage from received high power transmissions, and to possess as high a dynamic range as is feasible.
- RAS antennas should be designed with the lowest practicable sidelobe levels so as to permit observations to continue while the satellite radar is above the local horizon, although not directing its radar towards the RAS station.
- RAS data acquisition systems should be designed to log or flag instances of potential interference from the orbiting radar, based on known RAS and satellite operational parameters.
- RAS should continue to devote resources to extending the possibilities of real time or post-observation RFI mitigation techniques.

Annex 3

Excerpt from Resolution SFCG 24-2 “Use of the allocation for EESS (active) in the band 94 – 94.1 GHz”

RECOGNIZING

1. that avoidance of transmissions by EESS (active) missions in the band 94 – 94.1 GHz in case of main-to-main beam coupling with radio astronomy stations observing in the band 94-94.1 GHz may be necessary to avoid damage to radio astronomy receivers;
2. that not all currently planned EESS (active) missions in the band 94 – 94.1 GHz will be able to switch off their transmissions;
3. that avoidance of radio astronomy observations in the band 94 – 94.1 GHz in case of main beam-to-main beam coupling with an EESS (active) mission transmitting in the band 94 – 94.1 GHz may be necessary to avoid damage to radio astronomy receivers;
4. that avoidance of radio astronomy observations in the adjacent bands 92 – 94 GHz and 94.1 – 95 GHz when in line of sight of an EESS (active) mission transmitting in the band 94 – 94.1 GHz may be necessary to avoid detrimental interference to radio astronomy observations;
5. that the free and open availability of advanced operational schedule information on each and every EESS (active) mission in the band 94 – 94.1 GHz would facilitate the protection of the radio astronomy service;
6. that more than 30 radio astronomy telescopes worldwide (see Annex 2 for a non-exclusive list) will be potentially involved in observations in these bands, which are generally planned long (weeks to months) in advance;

RESOLVES

1. that the SFCG will provide the free and open means for member agencies to make advanced operational schedule information available and up-to-date via the official SFCG Web Site;
2. that member agencies submit such operational schedule information on intended spaceborne active sensing missions that will use the primary allocation in the 94 – 94.1 GHz band to the SFCG Web Coordinator;
3. that member agencies with active missions keep such operational schedule information up-to-date;
4. that member agencies and IUCAF use the mutual planning procedure given in Annex 1 to ensure the protection of radio astronomy service operations in the band 94 – 94.1 GHz.

Annex 4

Estimate of CPR power flux density levels on the ground

1 Power flux density at nadir

G_t = peak antenna gain = 66.9 dBi
P_t = transmit peak power = 33.4 dBW
h = altitude (perigee) = 398.4 km
θ = incidence angle = 0 degrees

$$PFD = \frac{P_t G_t}{4\pi}\left(\frac{1}{\frac{h}{cos\theta}}\right)^2$$

$$PFD\ (dB) = \ -22.7\ dB\left(\frac{W}{m^2}\right)$$

2 Power flux density at a generic direction

The power flux density at a generic direction can be computed using the equation above and the gain pattern for the CPR antenna, which is summarized in the following table:

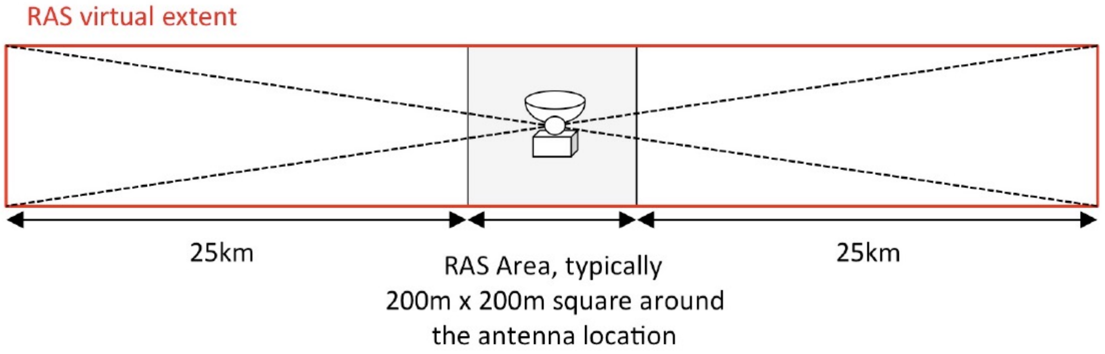
CPR Tx Parameters:	Values:
Antenna gain:	≧ 65.68 dBi 66.9 dBi peak
Beam width:	≦ 0.095 deg
Sidelobe levels:	≦ -17.3 dB <1 deg from beam center
	≦ -39.1 dB -7 to -1 deg, +1 to +7 deg
	≦ -47.5 dB -70 to -7 deg, +7 to +70 deg
Cross polarization level:	≧ 25 dB @beam center
Polarization:	LHCP

During all CPR operations, the CPR antenna will be kept pointing in nadir direction with an attitude uncertainty of ≦ 0.1059° around nadir axis. Taking into account the satellite attitude uncertainty, the CPR antenna can be modelized as a perfect nadir-pointing antenna with an equivalent main lobe aperture of 0.2009°, which is the sum of the nominal beam width (0.095 deg) and the pointing uncertainty (0.1059 deg).

On RAS station side, in accordance to sections 4.3.3 and 4.4 of [1]) each RAS station is modeled depending on the type of station by a RAS area as follow:

- RAS single-antenna stations are modeled by a squared RAS area of 200m by 200m centered on the antenna (to take into account antenna size and location uncertainty);
- RAS multiple-antenna stations are modeled by the smallest rectangle including all antennas plus an extra margin of 100m on each side; this area sizing information is expected to be duly provided in Table 2 that forms part of the main agreement.

In addition, considering that EARTHCARE in-orbit routine operations will be maintained into a ±25 km dead-band corridor (i.e. there is a ±25 km uncertainty in the longitude of the satellite), this RAS area is extended by an additional +/- 25km in an east-west direction as depicted below (figure extracted from [1]):



From a RAS point of view, the "worst case" corresponds to the CPR entering the Silent State mode when the main lobe is 1.52 km away from the RAS area. It is a "worst case" in the sense that the CPR could enter Silent State mode when it is further away from the RAS site. A distance of 1.52 km corresponds to CPR half main lobe beamwidth, and it includes uncertainties in the pointing of the CPR and in the location of the RAS site. The CPR table above specifies that outside of the main lobe the CPR antenna gains are at least 17.3 dB below the peak antenna gain. This value can be used to compute the PFD at the RAS site when the CPR main lobe is 1.52 km away from the RAS site (i.e. at the "RAS worst case").

Finally, it is also possible to compute the power received by each RAS site equipped with antennas of different diameters (as PFD x antenna surface).