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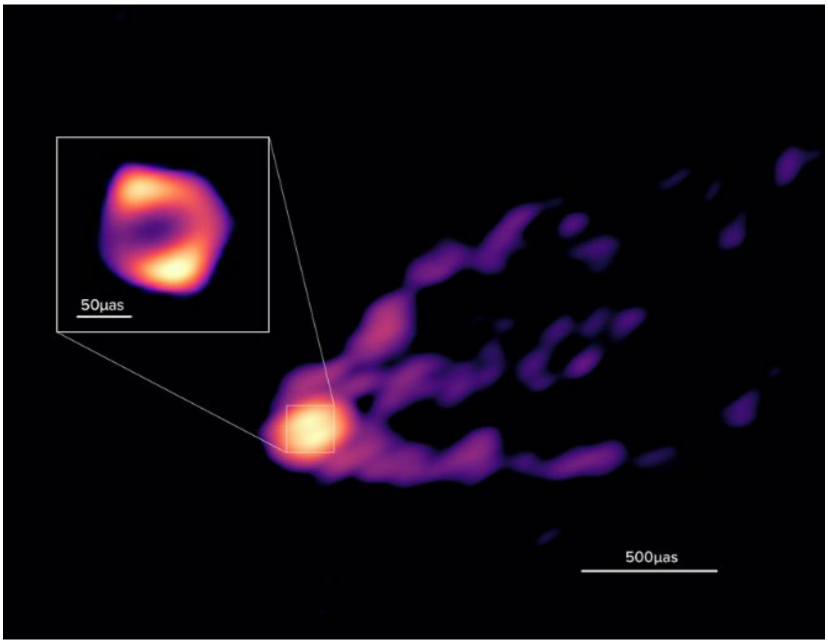
Onsala Space Observatory

The Swedish National Infrastructure for Radio Astronomy

Annual Report 2023



Reconstructed image of the region around the supermassive black hole in the centre of the galaxy M87, from data from a telescope network consisting of the Global Millimetre VLBI Array, including the Onsala 20 m telescope, and ALMA (Nature 616, p. 686, 2023).

Onsala, 19 August 2024

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CHALMERS UNIVERSITY OF TECHNOLOGY | ONSALA SPACE OBSERVATORY

Contents

This report describes the 2023 activities of the Onsala Space Observatory (OSO) infrastructure, covering both its operations related to radio astronomy (primarily funded by VR), and those related to geoscience (primarily funded by the Swedish land survey organization Lantmäteriet). The report is divided into the sections listed below. The sections/subsections that relate to radio astronomy contain a reference to the corresponding module(s) of the VR grant supporting that activity.

1 Operations

During 2023 Onsala Space Observatory (OSO) operated the following facilities:

- The Onsala 20 m telescope for astronomical Very Long Baseline Interferometry (VLBI), geodetic VLBI and single-dish astronomy
- The Onsala 25 m telescope for astronomical VLBI
- The Onsala LOFAR station as part of the International LOFAR Telescope (ILT) and in stand-alone mode
- The Atacama Pathfinder Experiment telescope (APEX) used for mm wave single-dish astronomy and mm-VLBI. From 2023 APEX is solely operated by the Max-Planck Institute for Radio Astronomy (MPIfR) but Sweden has, via a bilateral agreement with MPIfR 13 nights per year of observing time.
- The Nordic ARC node (the Atacama Large Millimeter/sub-millimeter Array Regional Centre node for the Nordic, and Baltic, countries)
- The Onsala Twin Telescope (OTT) for geodetic VLBI
- The Onsala gravimeter laboratory for absolute and relative gravimetry
- The Onsala GNSS stations
- The tide gauges at Onsala
- Two water vapour radiometers (WVR) supporting space geodesy

- The Onsala aeronomy station for observations of H_2O, CO, and O_3 in the middle atmosphere
- The Onsala seismometer station
- The Onsala time & frequency laboratory

Operations using the above facilities are described in more detail below under Telescopes (Sect. 1.1), Nordic ARC node (Sect. 1.2) and Geophysical instruments (Sect. 1.3).

1.1 Telescopes

[VR grant modules 3, 4, 5 and 6]

Below we describe the activities during 2023 of the radio telescopes located at Onsala and of the APEX telescope in Chile

Onsala 20 m telescope: The 20 m telescope was operated during the year according to plan. The telescope participated in 48 geodetic 24-hour campaigns, 9 astronomical single-dish projects, 5 extended astronomical VLBI sessions, and 2 teaching/outreach observations. Maintenance activities in the form of minor upgrades and repairs, as well as technical on-sky observations, were at normal levels. New elevation helical gearboxes were installed and commissioned along with a heater system to reduce friction in winter temperatures. This measure was deemed essential after the old gearboxes were seen to be nearing end-of-life when serviced, as described in the Onsala Activity Report 2022.

Onsala 25 m telescope: The Onsala 25 m telescope (see Fig. 1.1) was used for astronomical VLBI as planned without any major problems during the year (for details see VLBI summary below).

Figure 1.1. *The 25 m telescope in Onsala. Credit: Magnus Thomasson*

Onsala Twin Telescope (OTT): In 2023, The OTT was used for 24 VGOS sessions of 24 h duration and for 168 VGOS sessions of 1 h duration. See Sect. 1.3 for details.

APEX: The three-partner agreement to operate APEX between MPIfR, ESO and OSO ended on 31 December 2022. MPIfR continues as the sole institute of the original three partners operating the APEX telescope. As part of a new bilateral MPIfR-OSO agreement Swedish

SEPIA receivers will remain on the APEX telescope at least until the end of 2025. The same bilateral agreement guarantees Swedish access to APEX observing using the receivers that had facility status as of the end of the three-way project (i.e. SEPIA and nFLASH) for a total of 13 nights per year.

Given a significant reduction in Swedish APEX time from 2023 onward it was decided that the rules for APEX proposals on Swedish time must be more restrictive than previously. The former rules required a Swedish co-I, with a small fraction of open time (financed by EU transnational access funding till end of 2022). The new access rules starting in 2023 require a PI with a Swedish affiliation on all proposals for Swedish APEX time.

During 2023 Swedish APEX observations were conducted on 13 days organized mainly within three observing runs in May, July, and October. These observations were performed by Swedish astronomers at APEX (except in May) with the aid of remote support from Sweden and local APEX staff members.

LOFAR: The Onsala LOFAR station operates in two main observing modes: International LOFAR Telescope (ILT) mode and Single Station mode. In ILT mode, the network operates as a single interferometric telescope and data is correlated between stations. In Single Station mode no such correlation occurs, and the OSO LOFAR station usually observes independently from the rest of the array under OSO control (Single Station/Local observing). Observing time for this mode is allocated via proposals submitted to OSO. Some single station observing is also allocated via the ILT Call-for-Proposals (so-called Single Station/ILT observing). In either case, Single Station observing time is generally devoted to pulsar research, meteor shower observations, planetary and solar radio bursts, and space weather monitoring.

VLBI: Very Long Baseline Interferometry observations were conducted using the Onsala 25 m and 20 m telescopes, and by the OTT (Onsala Twin Telescope) as part of international networks of telescopes for astronomy and geodesy. The astronomical VLBI observations were scheduled based on recommendations from time allocation committees [for the 20 m and 25 m telescopes these TACs are the European VLBI Network TAC and the Global Millimetre VLBI Array (GMVA) TAC]. Geodetic VLBI observations using Onsala telescopes (20 m and OTT) were scheduled by the International VLBI Service (IVS).

The usage of the above telescopes was distributed in the following way:

– The Onsala 20 m telescope:	25 days of astronomical VLBI 48 days of geodetic VLBI (for details, see Sect. 1.3) 102 days of single-dish astronomy
– The Onsala 25 m telescope:	58 days of regular astronomical VLBI (in addition, observations were carried out on 42 days for the VLBI-campaign PRECISE and for magnetar monitoring, see Sect. 4.3)
– The Onsala Twin Telescope:	24 + 168 sessions of geodetic VLBI (for details, see Sect. 1.3)
– The APEX telescope:	13 days of single-dish astronomy on Swedish time
– The LOFAR station:	226 days ILT, 26 days Station/ILT, 47 days Station/Local so in total 73 days of single station observing

Note that time taken for "normal" technical service, pointing, etc. is not included in the above observing time values for each telescope. These service activities amounted to about 15 additional days on both the 20 m and 25 m telescopes respectively. Finally, an additional 14-21 days on the 20 m were exceptionally used in 2023 for stress-testing/wearing-in newly installed gearboxes.

1.2 Nordic ARC node

[VR grant module 2]

During 2023 the ALMA telescope celebrated a decade of science operations. To commemorate this 10-year anniversary a conference was held in December 2023 in Puerto Varas, Chile, including representatives of the Nordic ARC node staff and the Swedish community. During the year detailed plans to upgrade the ALMA telescope toward 2030 via the ALMA Wideband Sensitivity Upgrade (WSU) were unveiled: This is an ambitious upgrade to maintain the telescope at the forefront of millimetre/submillimetre astronomy into the next decade. The implementation of the WSU will have a significant impact on the telescope availability, on the user community and on the operations of the Nordic ARC node during the coming years.

The Call for Proposals for ALMA Cycle 10 took place in the spring of 2023. New capabilities for the ALMA Cycle 10 call included the possibility to apply for joint proposals with other observatories (VLA, JWST and VLT) and to observe with the new ALMA Band 1 receivers. The total number of submitted proposals globally was slightly smaller than previous years, but the requested observing time for the 12 m array continued its increasing trend. Overall, the oversubscription for the European region reached a factor of 8.4 (12 177 observing hours were requested opposed to the 1451 hours that were offered), which makes it extremely competitive to obtain ALMA time. Of a total of 1679 proposals submitted, 210 were co-authored by researchers based in Sweden and 54 of those proposals had a PI based in Sweden. As a result of the Proposal Review process, 11 projects led by astronomers based in Sweden were accepted. The Nordic ALMA Regional node staff based at Onsala served as Contact Scientists for a total of 16 Cycle 10 projects led by PIs with Swedish, Nordic, and Chilean affiliations.

With respect to operations, ALMA executed its 9th regular yearly cycle of observations, which ran from 1 October 2022 to 30 September 2023. Unfortunately, at the start of Cycle 10 the two ALMA antenna transporters suffered severe maintenance issues simultaneously which interrupted the scheduled execution of the Long-Baseline campaign (ALMA only moves antennas to the furthest locations once every two years).

The operations of the Nordic ARC node during 2023 consisted of providing various types of community support. During the year the ARC node had 17 face-to-face visits from colleagues in need of support to reduce and analyse ALMA data, covering from basic to very advanced support cases. Besides tailored scientific support, the node also provided users with computer support to host and process ALMA data, including resources allocated to a large archival project exploiting the public ALMA Science Archive (Rizzo et al. (2023), see the publications list).

As usual the node organized events to help PIs in preparing their Cycle 10 proposals. The node organized 3 proposal preparation days in April 2023 and provided direct support to 10 PIs in preparing their submissions, including several Large Programs. As part of OSO's contributions to the commemorations of the first 10 years of ALMA operations, the Nordic ARC node hosted a community event at Onsala on 24 May 2023. The event was well attended by our user community (59 participants) with representatives of all the local astronomy research groups and the OSO receiver group GARD. The node also continued with its series of online training sessions for users, I-TRAIN with the European ARC Network. Further details of these events are given in Sect. 10. With respect to communication, the node kept the community in the region informed about relevant news on ALMA and the node activities through its mailing list (which has about 80 subscribers).

Related to activities carried out by the node that are not directly visible to the community, the node contributed to the yearly testing of the ALMA Observing Tool and continued performing the Quality Assurance of ALMA datasets for projects with Swedish and Nordic PIs. In particular, the node specializes in the Quality Assurance of ALMA observations in polarization. This is an observing mode for which there is not yet an automatic data reduction procedure in place. Besides the data reduction of those datasets, the input from our node staff is relevant for the work being done to allow future versions of the ALMA Science pipeline to incorporate automated reduction of polarization projects into its workflows. In total the node executed the data reduction of 10 polarization observations in 2023. Also related to ALMA operations, two node staff members performed shifts as Astronomer on Duty on site in Chile, to gain understanding of the telescope operations end-to-end, and to establish and maintain links with the Joint ALMA Observatory in Chile. Staff members also participated in numerous meetings and activities of the European ALMA Regional Centre, as well as in the workshop "*Tuning to the High-Frequency ALMA Universe*" that took place in Leiden and was dedicated to the exploitation of the ALMA High Frequency bands.

The ARC node also provides support for software tools that have been developed in-house. In the case of the package UVMultiFit, the software was cited in 10 publications in 2023 and the team provided support for 6 users in using the tool. Further software developments included a new tool to help ALMA proposers to automatically identify duplicate observations in the ALMA Science Archive and produce relevant information for the observing setup. The tool has already been used internally by ALMA Contact Scientists for Large Programs to automatically generate plots of pointing and spectral setups, and to carry out other sanity checks for all the Scheduling Blocks at once. It is planned that the latter tool will have its public release in 2024. Another software tool, the Contact Scientist Tracker, was developed by the node team to generate automatic reports on the status of ALMA observations for the Contact Scientists. This tool was extensively used in a stable release during the full year, generating weekly reports and allowing Contact Scientist to follow-up their projects. The development plans for the Contact Scientist Tracker in 2024 are directed towards it being officially incorporated into the ALMA Integrated Report System.

Finally, in 2023 the node participated in several proposals for development projects to increase the capabilities of ALMA. These project proposals covered varied topics from expanding the Solar ALMA observing mode, providing Advanced Data Products for the ALMA Science Archive and developing tools to better visualize ALMA polarization data. Another project related to providing astronomer input into an instrumentation project to develop meta-surfaces as advanced optics components for millimetre wave antennas. Further details of all these R&D projects are given in Sect. 4.1.

1.3 Geophysical instruments

Geodetic VLBI:

Both the 20 m telescope and the OTT were used for making geodetic VLBI observations during 2023. The observing time, in particular for the OTT, remains limited due to international correlator capacity to process the data. The 20 m geodetic observations used its S/X receiver system in 24 h long observations within the IVS R1-, RD-, RV-, T2-series. In total 48 sessions within the IVS program were observed during 2023. One of these observed sessions did not result in useful data since the observatory experienced a severe power failure, causing problems with the VLBI systems. Two other planned sessions could not be observed due to telescope issues. All sessions were recorded with the DBBC2 in vdif-format on the FlexBuff recorder for geodetic VLBI. These data were then e-transferred to the respective correlator.

The Onsala twin telescopes (OTT) were used in 2023 for 24 international broadband VGOS sessions of 24 h duration each. Of these sessions, 20 were VGOS operational (VO) sessions and 4 VGOS Research and Development (VR) sessions. In the first three quarters of 2023, one VO or VR session was observed every 2nd week. Starting in October, VO or VR sessions were observed during 3 of 4 weeks in every month. During 16 of the 20 VO sessions both OE and OW were used in parallel. For 4 of the VO sessions, only OE was participating. For the 4 VR sessions both OE and OW participated. All data were recorded with the corresponding DBBC3 backends in vdif-format on dedicated FlexBuff recorders.

Additionally, a large number of VGOS intensive sessions of 1 h duration were performed. OE was used for 62 VGOS-INT-A sessions together with the partner station Kokee Park (K2, Hawaii, USA). In total 81 VGOS-INT-B2/C2 sessions were observed with both OE and OW and the partner station Ishioka (IS, Japan). Additionally, 20 VGOS-INT-B2/C2 sessions were observed using only OE and IS.

The VO-sessions were correlated at the correlators at MIT/Haystack (USA), USNO Washington (USA), MPIfR Bonn (Germany), Technical University Vienna (Austria) and Wettzell (Germany). The B2/C2-sessions were correlated at the Tsukuba correlator (Japan) and the VGOS-INT-A-sessions at USNO Washington (USA).

Additionally, during 2023 nine local interferometry sessions were observed using the OTT to monitor radio flux density of all ICRF3 defining sources that are visible from Onsala. For 5 IVS sessions observed with the 20 m telescope (ON), the OTT were tagged along to allow monitoring of the local ties between the three antennas. These so-called tag-along-ONTIE sessions were correlated and analysed at Onsala.

For the other non-VLBI geoscience facilities at Onsala the activities are summarised as follows:

GNSS stations:
OSO's primary GNSS station, called ONSA, has operated continuously during 2023. This is a station in the SWEPOS network operated by Lantmäteriet, the Swedish mapping, cadastral and land registration authority. ONSA is also one of the fundamental reference sites used in the global IGS network, as well as in the European EUREF network. An additional station, ONS1, has also delivered data continuously to the same networks. In addition to ONSA and ONS1, the six GNSS stations close to the Onsala twin telescopes all ran continuously during the year.

Gravimeter laboratory:
The main purpose of the gravimeter laboratory at Onsala is to maintain a gravity reference and calibration facility co-located with space geodetic techniques. The facility is one component of the Fundamental Geodetic Station. The laboratory is furnished with platforms for visiting absolute gravimeters (AGs), which happens on average one to three times per year. In 2023, we had one visit of Lantmäteriet with their absolute gravimeter in week 18. The OSO gravimeter laboratory's primary instrument is a superconducting gravimeter (SG, model GWR 054). In international context the instrument is called OSG054 and has been operated continuously with very few breaks in recording (less than 10 days) since its installation in June 2009. The one-minute sampled gravity data are uploaded monthly to the International Geodynamics and Earth Tide Service (IGETS) servers and contribute to the global SG data base, together with 41 other SG around the world.

Since 2022, the SG also has its own DOI, which should be cited when its data (available through the IGETS portal) are used. The DOI page is available here: https://dataservices.gfz-potsdam.de/igets/showshort.php?id=280b90c6-27ae-11ed-88a2-c7c587541054. More and more journals encourage/require authors to include data citations as part of their reference list. This should help to enhance the visibility of our SG data and to monitor their usage.

Tide gauges:
The Onsala tide gauge station ran uninterrupted for the entire year, excluding the yearly cleaning of the well causing a data gap of less than 2 hours on 25 August. The sea level observations are available in real time from the official web site of national sea level data operated by the Swedish Meteorological and Hydrological Institute (SMHI). The annual update of the maintenance plan was carried out together with SMHI's staff on 22 March. The Swedish Mapping, Cadastral and Land Registration Authority carried out a levelling campaign of the tide gauge in terms of the reference markers relative to the sea level on 21 May. Onsala's other GNSS-based tide gauge was also operated continually over the year proving observations with a sampling rate of 1 Hz. Data are stored in Receiver Independent Exchange Format (RINEX) format and include multi-GNSS (i.e., GPS, GLONASS, Galileo, Beidou) code- and carrier-phase observations, as well as signal-to-noise ratio (SNR) measurements.

Water Vapour Radiometers:
The water vapour radiometer Konrad measures the sky brightness temperatures at 20.7 GHz and 31.4 GHz from which the radio wave propagation delay due to water vapour in the atmosphere can be inferred. During 2023 Konrad operated almost continuously, there were just a few data gaps due to internet/communication failures, totalling a couple of days. The main reason for this loss of data was due to rain, or very heavy clouds, in the observed volume of air, which caused the retrieval algorithm to suffer from large uncertainties.

In May, a new radiometer was installed. It is called Greta and observes the sky brightness temperatures in 14 different frequency bands between 22 and 58 GHz. Greta operates in parallel to Konrad. While Greta most of the time performs line-of-sight observations coordinated with the Onsala radio telescopes during geodetic VLBI experiments, Konrad continuously maps the sky. For more information, see Sect. 4.6.

Aeronomy station:
The aeronomy station consists of two radiometers: 1) The single sideband H_2O system (water vapour) that measures the sky brightness temperature at 22 GHz, and 2) the double sideband CO/O_3 system (carbon monoxide and ozone) that measures the sky brightness temperatures at 111 and 115 GHz. Spectra from both radiometer systems are used to retrieve vertical profiles of the observed molecules in the middle atmosphere. During 2023 both radiometers operated without problems, which means that we have about 340 days of collected H_2O and CO/O_3 measurements.

Seismometer station:
OSO hosts a seismograph station which participates in the Swedish National Seismic Network (SNSN) led by Uppsala University. We have data access to the local seismometer and keep a continuous archive of its recordings. The station's waveform files are used in delay calibration of the superconducting gravimeter and for noise reduction in absolute gravity measurements.

Time and frequency laboratory:
The time and frequency laboratory hosts the hydrogen maser, which is necessary for VLBI observations, but which also contributes to the universal atomic time. OSO also collaborates with RISE (Research Institutes of Sweden) on contributing to the Swedish time-keeping system. RISE owns a second hydrogen maser and a cesium clock that are installed at Onsala. These instruments are used for comparison measurements and to provide redundancy for accurate

reference time (and frequency) for the VLBI observations (both astronomy and geodesy) at the observatory.

InSAR reflectors:
Two corner reflectors for Interferometric synthetic aperture radar (InSAR), provided to OSO by Lantmäteriet, were during the year permanently installed on bedrock at the observatory (see Fig. 1.2).

Figure 1.2. *The two corner reflectors for InSAR, with the radome housing the 20 m telescope in the background. Credit: Magnus Thomasson*

2 Key numbers

2.1 Astronomy

[VR grant modules 2, 3, 4 and 5]

Detailed key numbers for the astronomy activities are given in tables at the end of this report and in a separate excel file. Here we give only a few comments, a summary of the publication statistics, and some key numbers for single-dish observations with the 20 m telescope.

Users of the astronomy research infrastructure
The ALMA user project/user statistics given at the end of this report and in the associated excel file are for Proposal Cycle 9; that is for observations in the period October 2022 – September 2023. In conjunction with the annual ALMA deadline the Nordic ARC node is very active in advertising the use of ALMA in Sweden and the Nordic countries, and a significant number of Nordic/Swedish ALMA project proposals are generated by these Nordic ARC publicity efforts.

We note that for ALMA, APEX, astronomical VLBI, and LOFAR taken together, slightly less than one quarter of the Swedish users (individuals, proposed projects) were from other institutions than Chalmers. We only have limited information about the gender of all users of all telescopes, but the limited information we have indicate that about 30 % of the users are women.

Number of refereed scientific papers

An associated excel file gives a list for each instrument of *papers in refereed journals published in 2023* (see also the publication list at the end of this report). Conference publications are not included (except for a few technical publications). Below are given summary statistics of papers for each instrument/activity. For each instrument /activity two figures are given; in most cases the first number is the total number of instrument-related publications while the second is the number of publications with at least one Swedish author. In contrast for total ALMA papers and for ALMA papers with Nordic ARC node support the first number given is the number of papers with at least one Nordic author.

The Nordic ARC provides standard support for all projects with Nordic PIs, and further dedicated support upon request. The level and type of Nordic ARC node support for each publication is described in the accompanying excel file. Alongside the total numbers for Nordic/Swedish ALMA publications below, on the following line we give the total number of papers with at least one Nordic/Swedish author that have received dedicated Nordic ARC node support. The dominant reason that the number of papers receiving Nordic ARC support is significantly smaller than the total number of ALMA papers authored by Nordic/Swedish scientists is that most of those publications used ALMA data from projects that were not led by Nordic PIs, and therefore received support from other ALMA Regional Centres. Finally, we give below numbers for papers that make use of the ALMA Band 5 receiver that was designed and built by the OSO GARD unit; again with two numbers given, one for the total number of papers globally and a second one giving the number of Swedish authored papers.

For APEX, publications based on all partners' observing time are counted because OSO contributes to the full APEX operations costs and because the Swedish built and maintained receivers on APEX that are used by all partners. The numbers for astronomical VLBI papers include observations with EVN, GMVA, EHT and for users of JIVE. Publications by OSO staff on technical R&D are also listed below. A complete list of all publication in the categories below can be found at the end of this report.

• ALMA	119/57	(*Nordic/Swedish)*
ALMA - ARC node support	20/11	(*Nordic/Swedish)*
ALMA - Band 5	20/4	(*total/Swedish)*
• APEX	49/9	*(total/Swedish)*
• Astronomical VLBI	48/17	*(total/Swedish)*
• LOFAR	124/8	*(total/Swedish)*
• 20 m telescope, single-dish	6/4	*(total/Swedish)*
• Technical publ. by OSO staff	13	

In addition, in 2023 there were two publications using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), and two publications using data from the Swedish-ESO Submillimetre Telescope *SEST* (closed in 2003).

Onsala 20 m telescope, single-dish observations

Single-dish observations with the 20 m telescope in Onsala are not core national infrastructure activities (though maintaining the single dish mode is essential for calibrating core VLBI observations) so key numbers for these observations are not given in the tables at the end of this report. We note that in 2023, proposals for 8 projects were observed. There were 5 female and 9 male users on the observed projects. Of these, 9 were Swedish (8 of them from Chalmers).

2.2 Geosciences

Users of the geoscience research infrastructure

The OSO geoscience instruments, including the geodetic VLBI observations as the OSO's largest activity, do not have individual scientific users who apply for observing time. Rather the geoscience instruments make long-term measurements of Earth parameters – which are thereafter stored in international databases with open access. Since these databases are open access, it is impossible for us to acquire detailed insight in the user groups in terms of which universities or other organisations they belong to and the gender distribution of the users.

The OSO data and derived products delivered to geoscience databases such as station positions, Earth's orientation, rotation rate and gravity field are used both by the global geophysics community for scientific purposes and by civil society for a variety of practical applications including supporting accurate geo-location services and monitoring of global change.

Number of refereed scientific papers

We have identified 7 papers with one or more Swedish authors and 19 papers with non-Swedish authors published during 2023 in which the use of data or services from OSO are specifically stated. A publication list of these papers is given at the end of this report. In addition, there are significantly more papers making use of OSO data products, especially those using GNSS reference data from OSO via IGS/EUREF, that cannot be identified because the inclusion of the OSO station is not explicitly mentioned. It is also likely that there are papers published that we simply are not aware of. We are not aware of any patents originating directly from our geoscience activities. No user has been rejected to use OSO geoscience data; this is in any case not a readily computable statistic since as described above virtually all the OSO geoscience data are automatically distributed via open data bases.

Data submissions

Geodesy VLBI:

The geodetic VLBI observations are carried out within the framework of the International VLBI Service for Geodesy and Astrometry (IVS), http://ivscc.gsfc.nasa.gov. In total 48 experiments, each one with a length of 24 h and rather evenly spread over the year, were carried out during 2023 with the Onsala 20 m telescope. Additionally, we have been observing with the Onsala twin telescopes during several VGOS sessions; 24 international 24 h sessions and 168 one-baseline intensive sessions (1 h long).

Correlated VLBI observations are provided via the IVS data archives and are available free of charge. The IVS registers its data also under the umbrella of the World Data System (WDS), which is an Interdisciplinary Body of the International Council for Science (ICSU). Databases as well as products are supplied to users around the globe with minimum latency to guarantee that operation critical information, particularly Earth orientation parameters from VLBI observations, are available for satellite operators, space agencies, and other stakeholders. These databases are fundamental for many scientific disciplines within Geophysics. Given also that global navigation satellite systems like GPS and Galileo, would not be operable without the Earth orientation parameters provided from VLBI measurements, the true value chain and the number of users of products emerging from data collected at globally distributed VLBI sites like Onsala, has significant economic value to society; given that everybody relying on GNSS positioning and navigation has in the end use of the data.

GNSS:
The two major GNSS reference stations at OSO, i.e. ONSA and ONS1, are nodal points for the Swedish permanent GNSS network, SWEPOS, hosted by Lantmäteriet. All data acquired continuously are openly distributed via the data archives of IGS https://webigs.ign.fr/gdc/en/, and EUREF http://www.epncb.oma.be/. These archives serve thousands of users every year. Additionally, GNSS data are recorded with six stations distributed around the Onsala twin telescopes, called OTT1 to OTT6 with data stored at Lantmäteriet. It should be noted that the need for using GNSS data from OSO is motivated by the fact that the stations are co-located with one of the most accurately determined VLBI stations world-wide. Therefore, indirectly also the VLBI data are used via the GNSS data from OSO. Many cases are found in the research community where GNSS data are used with OSO acting as a reference site in global, regional and local studies. A vast majority of the downloads, that occur from the international databases operated by IGS and EUREF, are by universities and research agencies for studies of, *e.g.*, plate tectonics, crustal deformation, space weather, sea level, climate, meteorological monitoring, *et cetera*. Thus, OSO provides both the national and international user communities with a robust and accurate link to the international reference frame. Also, during 2023 the GNSS station OSOI has been operated and contributed to ESA’s ionospheric monitoring network.

Gravimeter Laboratory:
OSO gravimeter data with one-second samples and with a maximum of two-minutes latency are publicly available, see http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html. The records are also submitted to the archive of IGETS (International Geodynamics and Earth Tide Service) at GeoForschungsZentrum (GFZ) Potsdam (Germany), on a monthly routine. OSO delivers 1-minute down-sampled data, raw and “corrected” data, i.e., cleaned from earthquake signatures. IGETS is a service under the auspices of the International Association of Geodesy (IAG). In 2023, we had one visit of Lantmäteriet with their absolute gravimeter in week 18. Since 2022, the SG also has its own DOI, which should be cited when its data (available through the IGETS portal) are used. The DOI page is available here: https://dataservices.gfz-potsdam.de/igets/showshort.php?id=280b90c6-27ae-11ed-88a2-c7c587541054.

Ocean tide loading service:
Since 2002, OSO provides a computing service for ocean tide loading effects in application to surface displacements and gravity (http://holt.oso.chalmers.se/loading). This service is endorsed by the IERS; its main purpose being to provide consistent reduction of these effects to VLBI, GNSS and SLR analysis centres in their preparation of products that maintain the ITRF. Apart from this, the service’s logbook hints at many users peripheral or outside the ITRF community in their analysis of GNSS observations. Loading-induced displacements are computed from a range of global ocean tide maps, using 28 sources featuring 8 to 11 tide species each.

Tide gauges:
The data from the OSO super tide gauge are transferred to SMHI in near-real time. The sea level observations are available in real time from the official web site of national sea level data operated by the Swedish Meteorological and Hydrological Institute (SMHI). The Onsala tide gauge station ran uninterrupted for the entire year during 2023, excluding the yearly cleaning of the well which caused a data gap of less than 2 hours on 25 August. The annual update of the maintenance plan was carried out together with SMHI's staff on 22 March. The Swedish Mapping, Cadastral and Land Registration Authority carried out a levelling campaign of the tide gauge in terms of the reference markers relative to the sea level on 21 May.

Aeronomy station:
During 2023 both radiometers operated without problems, which means that we have about 340 days of collected H_2O and CO/O_3 measurements. These data are being processed to be delivered to the Network for the Detection of Atmospheric Composition Change (NDACC; see http://www.ndsc.ncep.noaa.gov).

3 Selected scientific highlights

This section contains a list of scientific highlights selected to illustrate the different instruments and science areas covered by OSO. Especially highlighted are papers from Swedish scientists using Onsala telescopes and other instruments, or using APEX, or receiving user support provided at OSO (via for instance by the Nordic ARC node). In the listed publications Swedish authors are shown underlined.

3.1 ALMA

[VR grant module 2]

The heart of Sakurai's object revealed by ALMA
Tafoya, D., van Hoof, P. A. M., Toalá, J. A., Van de Steene, G., Randall, S., Unnikrishnan, R., Kimeswenger, S., Hajduk, M., Barría, D., Zijlstra, A.
Astronomy & Astrophysics, vol. 677, p. L8 (2023)

Summary: This paper discusses high-resolution ALMA observations of Sakurai's object, providing insights into its morpho-kinematic structure. Stars up to 8 solar masses often experience a “final helium shell flash” during their transition to white dwarfs, leading to a “born-again event”. Sakurai's object is a rare example observed during this process. Initial observations suggested a bipolar ejecta structure with a dust disc. ALMA's observations at 20 milliarcsec resolution revealed a compact, bright central component made of amorphous carbon dust, likely the dust disc seen in earlier mid-infrared observations. At 300 milliarcsec resolution, a bipolar structure with north-south velocity gradient was observed, indicative of an expanding disc and bipolar molecular outflow (see Fig. 3.1). The observations allowed us to calculate the inclination of the disc and determine its expansion velocity and a radius. The bipolar outflow’s expansion velocity is around 1000 km/s, with an hourglass shape. These findings show the development of an equatorial disc and bipolar outflows in Sakurai's object post-born-again event, offering valuable data for future stellar evolution modelling.

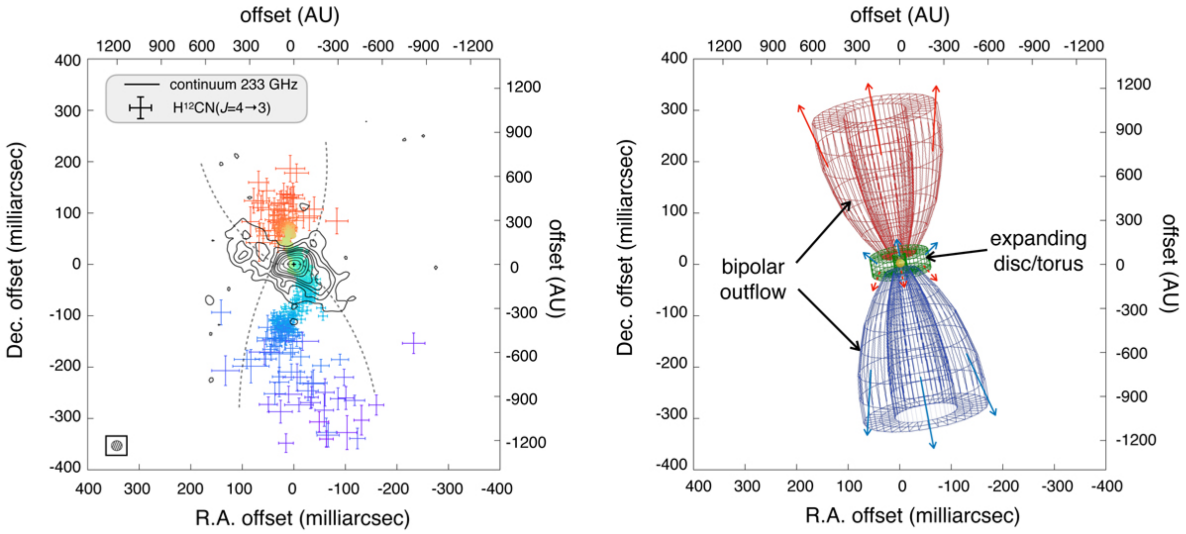


Figure 3.1. *Bipolar outflow and expanding disc around Sakurai's object. Left: $H^{12}CN(J = 4 \rightarrow 3)$ line emission and 233 GHz continuum emission. The dashed lines delineate the hourglass morphology suggested by the continuum emission. Right: Hourglass model for the spatial-kinematical distribution of the bipolar outflow in Sakurai's object. The right and top axes indicate the linear scale assuming a distance of 3.5 kpc to the source.*

Exploring the environment, magnetic fields, and feedback effects of massive high-redshift galaxies with [C II]
Kade, K., Knudsen, K. K., Vlemmings, W., Stanley, F., Gullberg, B., König, S.
Astronomy & Astrophysics, vol. 673, p. 116 (2023)

Summary: Here, the authors present ALMA band-7 observations of two massive high-redshift galaxies, AzTEC-3 and BRI 0952-0115, to place them in the broader context of galaxy evolution, specifically star formation and mass growth through cosmic time. High-redshift starburst galaxies and quasars are thought to be transformative evolutionary phases during the growth process of massive galaxies and thus provide insight into galaxy evolution. Polarisation observations of the [CII] emission line presented here yield no detection of strong, ordered magnetic fields at the kiloparsec scale in the two studied sources. However, a study of the line profiles indicates the possible presence of massive outflows in BRI 0952-0115 and AzTEC-3; however, the presence of companion galaxies could also affect this interpretation. Evidence of a "gas bridge" between AzTEC-3 and a companion source is found as well. The investigation of the possible role of the detected companions in outflow signatures, using a simple dynamical mass estimate for the sources, suggests that both systems are undergoing galaxy interactions. These findings provide additional evidence in support of the hypothesis that massive galaxies form in over-dense regions, growing through minor or major mergers with companion sources.

The opaque heart of the galaxy IC 860: Analogous protostellar, kinematics, morphology, and chemistry
Gorski, M. D., Aalto, S., König, S., Wethers, C., Yang, C., Muller, S., Viti, S., Black, J. H., Onishi, K., Sato, M.
Astronomy & Astrophysics, vol. 670, p. 70 (2023)

Summary: The paper presents results from a high-resolution ALMA study of the molecular gas kinematics, morphology and chemistry in IC 860, a luminous infrared galaxy with a compact obscured nucleus (CON). These galaxy nuclei are compact, with radii of 10–100 pc, with large optical depths at sub-mm and far-infrared wavelength. CONs represent an extreme phase of nuclear growth, hiding either a rapidly accreting supermassive black hole or an abnormal mode of star formation. Principal component analysis (PCA) tomography, a technique to unveil correlations in the parameter space of a dataset is applied to explore the morphological and chemical properties of different molecules in the 0.06"-resolution data. The PCA analysis reveals a complex structure in the central ISM of IC 860: a rotating, infalling disk or envelope is found, as well as an outflow analogous to those seen in Galactic protostars. One molecule, methanimine (CH_2NH), yielded especially interesting results as it suggests that CONs are an important stage of chemical evolution in galaxies that are chemically and morphologically similar to Milky Way hot cores.

3.2 APEX

[VR grant module 3]

Molecular Outgassing in Centaur 29P/Schwassmann-Wachmann 1 during Its Exceptional Outburst: Coordinated Multiwavelength Observations Using nFLASH at APEX and iSHELL at the NASA-IRTF
Roth, N. X., Milam, S. N., DiSanti, M. A., Villanueva, G. L., Faggi, S., Bonev, B. P., Cordiner, M., Remijan, A. J., Bockelée-Morvan, D., Biver, N., Crovisier, J., Lis, D. C., Charnley, S. B., Jehin, E., Wirström, E. S., McKay, A. J.
The Planetary Science Journal, vol. 4, p. 172 (2023)

Summary: APEX CO(J=2-1) observations of the periodic comet 29P/Schwassmann-Wachman 1 (29P/SW1) following an outburst in 2021 showing variations between the first days of observation, see Fig. 3.2. Only CO was detected although several other molecules were also targeted. Together with the rovibrational CO lines coma properties such as rotation temperature, coma kinematics and CO production rates could be determined.

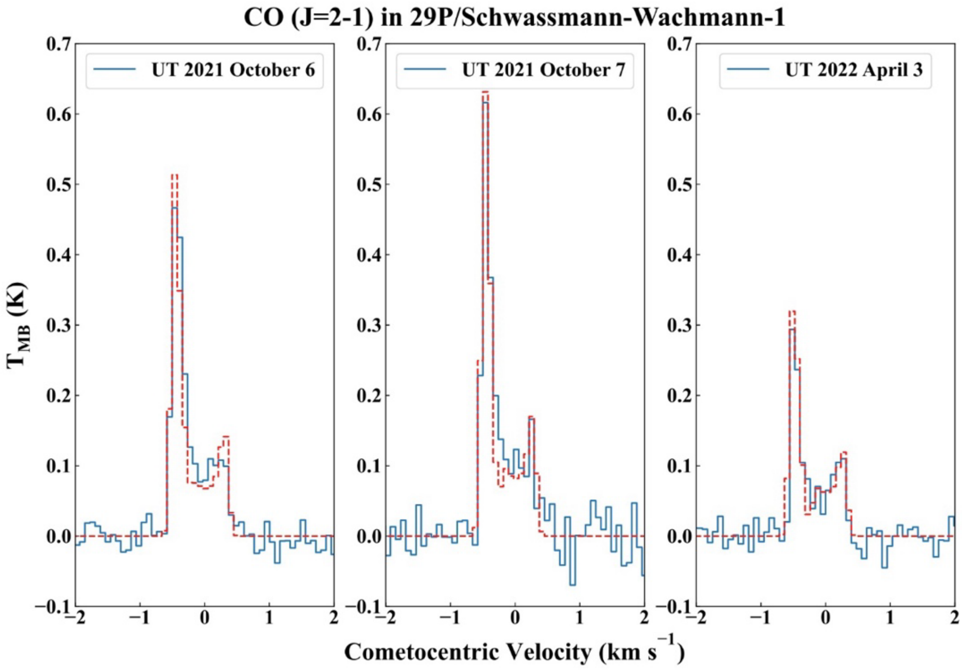


Figure 3.2. *CO(2-1) spectra of the periodic comet 29P/SW1 in October 2021 and in April 2022. Blue lines indicate the observations with the nFLASH230 receiver at APEX and red lines are results from the radiative transfer models. The asymmetry of the outflow originates from the stronger sunward facing component.*

Linking ice and gas in the Coronet cluster in Corona Australis
Perotti, G., Jørgensen, J. K., Rocha, W. R. M., Plunkett, A., Artur de la Villarmois, E., Kristensen, L. E., Sewilo, M., Bjerkeli, P., Fraser, H. J., Charnley, S.B.
Astronomy & Astrophysics, vol. 678, p. A78 (2023)

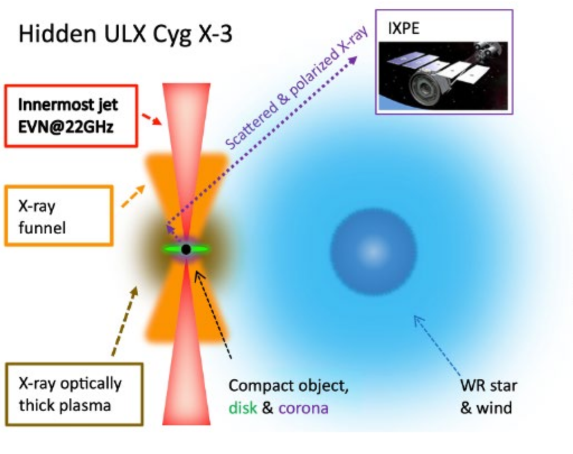
Summary: SMA and APEX observations were presented of several methanol lines at 1 mm of four low-mass protostars in the Coronet cluster. APEX data served as zero spacing input to the images to highly improve the abundance estimations needed for obtaining gas-to-ice ratios in this strongly irradiated cluster. The estimated gas-to-ice ratios are found to be like those in less irradiated regions.

3.3 Astronomical VLBI

[VR grant module 4]

The innermost jet in the hidden ultra-luminous X-ray source Cygnus X-3
Yang, J., Garcia, F., del Palacio, S., Spencer, R., Paragi, Z., Castro, N., Biping Gong, S., Cao, H., Chen, W.
Monthly Notices of the Royal Astronomical Society, vol. 526, p. L1 (2023)

Summary: As a rarely seen Galactic high-mass X-ray binary, Cyg X-3 hosts a compact object (possibly a black hole) actively accreting matter from a very hot Wolf-Rayet star. X-ray polarization observations show that Cyg X-3 is most likely a hidden ultra-luminous X-ray (ULX) source with a luminosity above the Eddington limit along the direction of an optically thin X-ray funnel. With the participation of the Onsala 20 m telescope, recent EVN observations of Cyg X-3 at 22 GHz uncovered an elongated jet structure in the quiescent radio state for the first time, see Fig. 3.3. More interestingly, the jet position angle is fully consistent with the X-ray tunnel direction, indicating that the radio jet propagates along and within the X-ray funnel. The finding provides an unprecedented view of the complex central engines of ULXs.



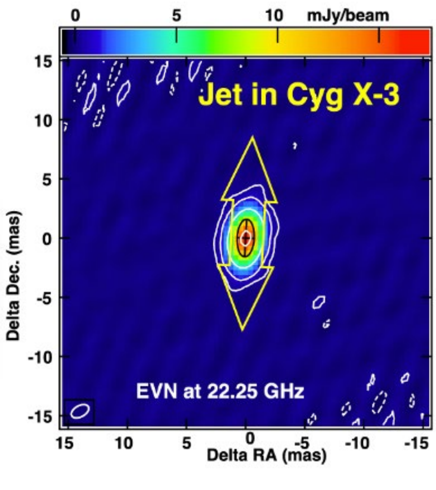


Figure 3.3. *Left: Schematic view of the inner structure of the Galactic hidden ULX Cyg X-3. Right: The innermost jet observed with the EVN at 22 GHz. The yellow arrow marks the direction of the radio jet and the optically thin X-ray funnel. The black ellipse shows the best-fitting elliptical Gaussian model and the sizes of the inner cross represent the full width at half maximum (FWHM). The map beam has an FWHM of 1.60 x 0.94 mas at PA = -61.5 degree and is also plotted in the bottom-left corner. The white contours plot the levels of (-1, 1, 4, 16, 64) x 0.24 mJy/beam. The map peak brightness is 17.3 mJy/beam.*

A ring-like accretion structure in M87 connecting its black hole and jet
Lu, R.-S., ..., Lindqvist, M., ..., Conway, J., ..., Yang, J., et al.
Nature, vol. 616, p. 686 (2023)

The Onsala 20 m telescope took part in 3.5 mm wavelength observations of the supermassive black hole at the centre of galaxy Messier 87 together with 13 other telescopes in the global millimetre array GMVA. High-resolution imaging of the data shows a ring-like structure of about 8.4 Schwarzschild radii in diameter, approximately 50 % larger than that seen at 1.3 mm with the Event Horizon Telescope. The outer edge of the ring at 3.5 mm is also significantly larger than that at 1.3 mm. This larger and thicker ring indicates a substantial contribution from emission from an accretion flow combined with absorption effects, in addition to emission from the gravitationally lensed ring-like emission seen at shorter wavelengths. The new image also shows for the first time how the edge-brightened jet in M87 connects to the accretion flow of the black hole. (See Fig. 3.4.)

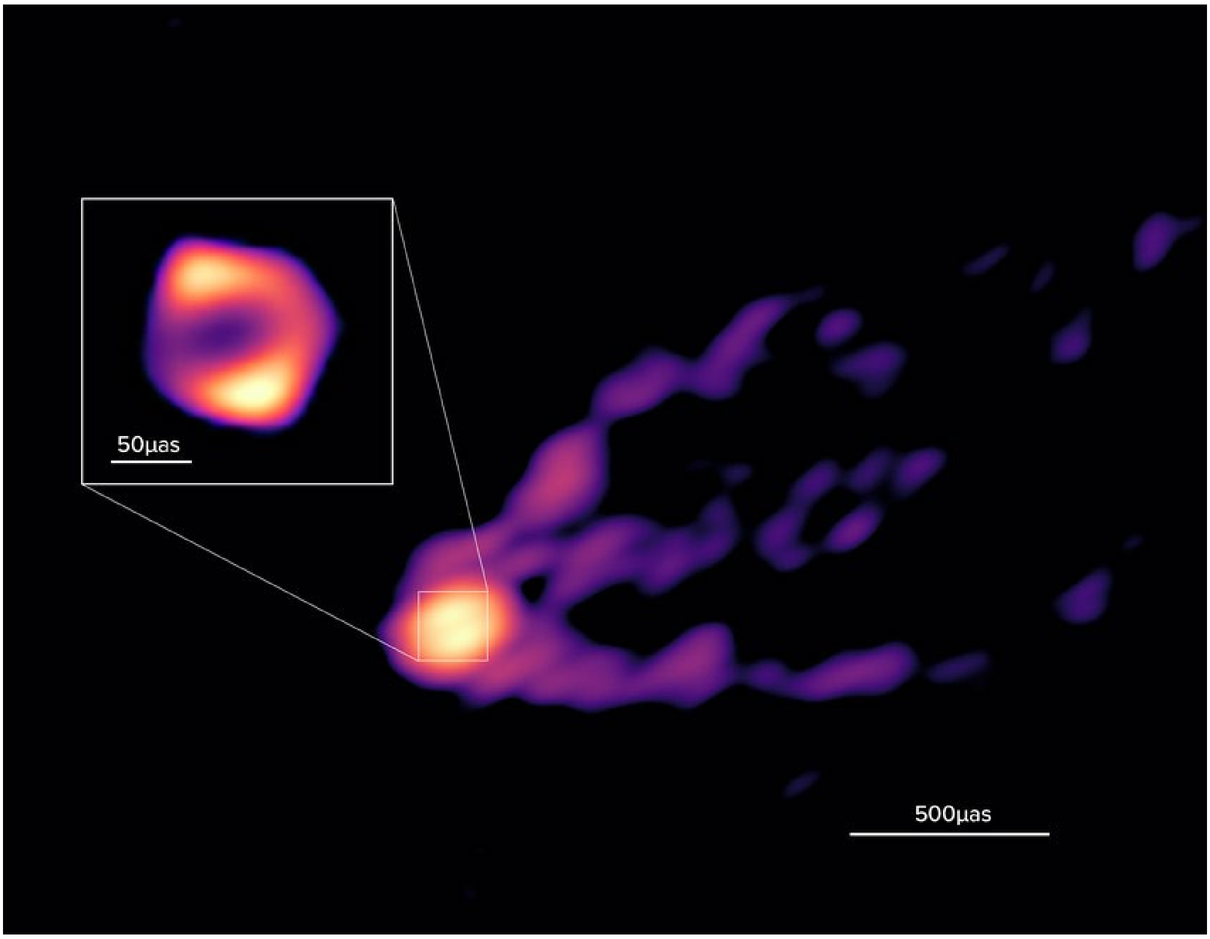


Figure 3.4. *Reconstructed image of the central region of M87 from data from the telescope network consisting of the GMVA plus ALMA. The large image shows a bright core with the black hole at its centre. The jet, recognisable as three filaments, two marking the edges of the jet outflow and the third the jet spine, is anchored in this core and originates there. An enlargement of the core in the highlighted box shows the ring structure of matter surrounding the black hole. The ring has an angular diameter of 64 microarcseconds, comparable to the diameter of a concert spotlight on the moon as seen from Earth.*

3.4 LOFAR

[VR grant module 5]

A Simultaneous Dual-site Technosignature Search Using International LOFAR Stations

Johnson, O.A., Gajjar, V., Keane, E.F., McKenna, D.J., Giese, C., McKeon, B., Carozzi, T.D., Alcaria, C., Brennan, A., Brzycki, B., Croft, S., Drew, J., Elkins, R., Gallagher, P.T., Kelly, R., Lebofsky, M., MacMahon, D.H.E., McCauley, J., de Pater, I., Raeside, S.R., Siemion, A.P.V., and Worden, S.P.

Astronomical Journal, vol. 166, p. 193 (2023)

Summary: For the first time, two identical radio telescopes (LOFAR stations) at two different geographical locations (Sweden & Ireland) made simultaneous SETI (Search for Extra-Terrestrial Intelligence) observations. The novelty of simultaneous observations on identical stations is signals of no interest (such as man-made radio frequency interference) can be rejected if only present at one of the sites. This is extremely useful since man-made signals are often confused as potentially extra-terrestrial intelligent signals, but since the Swedish and Irish station are so far apart, one cannot expect the same source of RFI at both sites. Setting up simultaneous measurements at both stations required the use of software developed at Onsala, called iLiSA that can send the same operational commands to both stations.

The LOFAR Tied-Array All-Sky Survey: Timing of 35 radio pulsars and an overview of the properties of the LOFAR pulsar discoveries

van der Wateren, E., Bassa, C.G., Cooper, S., Grießmeier, J.-M., Stappers, B.W., Hessels, J.W.T., Kondratiev, V.I., Michilli, D., Tan, C.M., Tiburzi, C., Weltevrede, P., Bak Nielsen, A.-S., Carozzi, T.D., Ciardi, B., Cognard, I., Dettmar, R.-J., Karastergiou, A., Kramer, M., Künsemöller, J., Osłowski, S., Serylak, M., Vocks, C., and Wucknitz, O.

Astronomy & Astrophysics, vol. 669, p. A160 (2023)

Summary: This paper summarized a survey called LOTASS, which is "...the most sensitive untargeted radio pulsar survey performed at low radio frequencies (119−151 MHz) to date...". It has discovered 76 new pulsars including a pulsar which was up until recently the slowest pulsar ever recorded with a pulse period of 23.5 s. Onsala helped by providing beam polarization correction software and setting up of the pulsar observations on the Swedish LOFAR station. (See Fig. 3.5.)

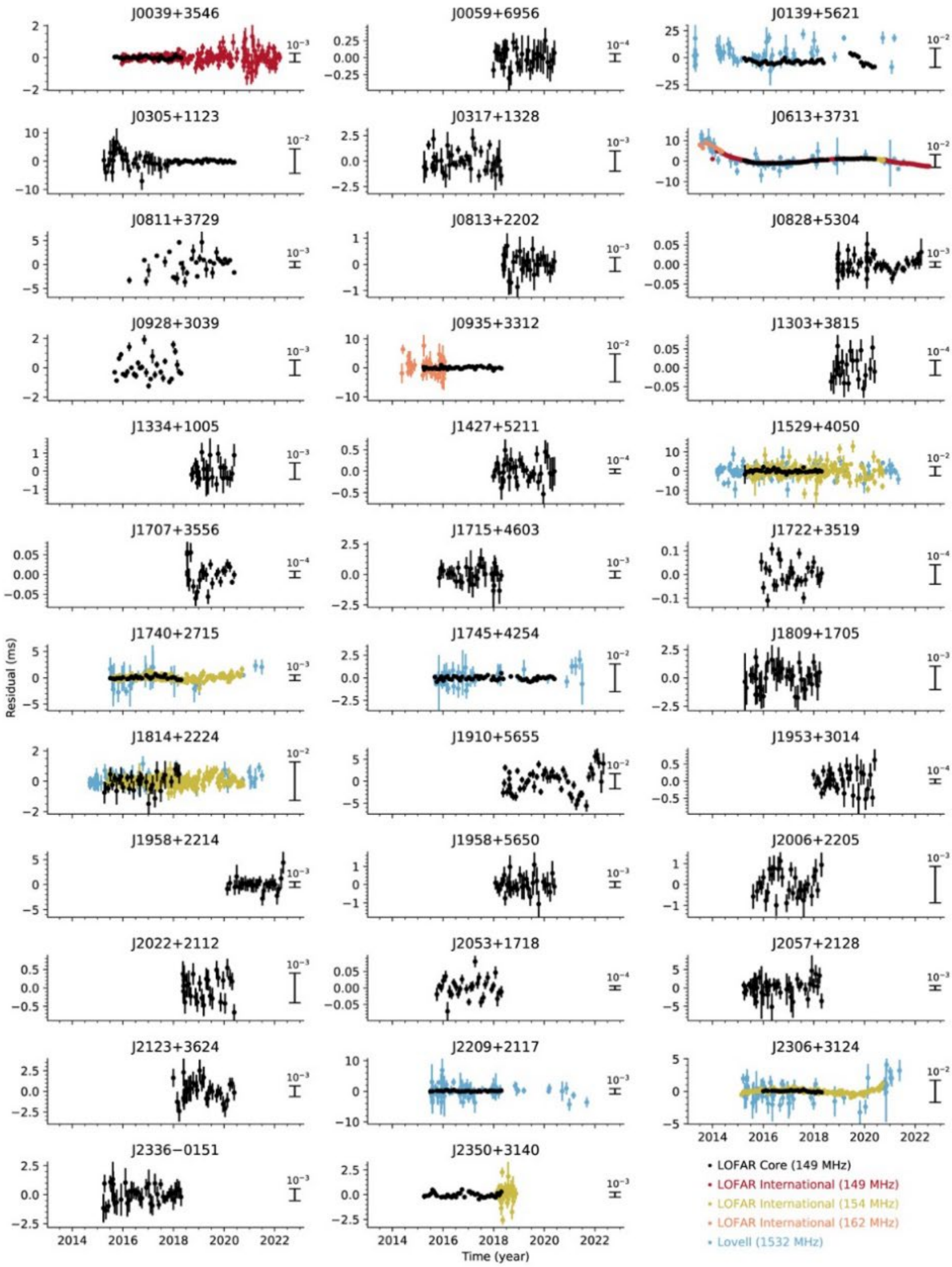


Figure 3.5. *Some of the many pulsars in the LOTASS survey.*

3.5 Onsala 20 m telescope single dish

Deep search for glycine conformers in Barnard 5
Carl, T., Wirström, E.S., Bergman, P., Charnley, S.B., Chuang, Y.-L., and Kuan, Y.-J.
Monthly Notices of the Royal Astronomical Society, vol. 524, p. 5993 (2023)

Summary: Very low column density limits were measured for the biologically important organic molecule glycine, NH_2CH_2COOH, using the 4 mm receiver on the 20 m telescope. Stacking of the many line positions from this rich spectrum molecule was employed in order to reach the most sensitive abundance limit in a cold low-mass source, $\leq (0.7–3) \times 10^{-11}$ in Barnard 5. This result helps guide the endeavour to understand the origin of glycine we have found in meteorites and comets in the Solar system. (See Fig. 3.6.)

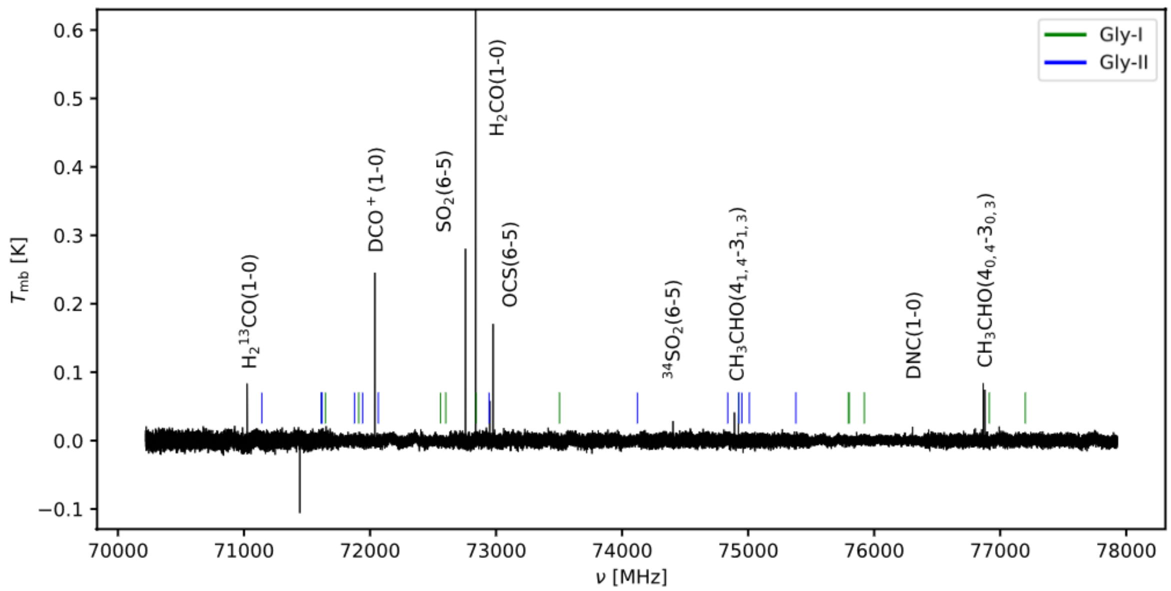


Figure 3.6. *Spectrum of Barnard 5 taken with the 20 m telescope. The blue and green vertical lines indicate the frequencies of two different "flavours" of glycine related to the orientation of the chemical bonds within the molecule.*

Similar levels of deuteration in the pre-stellar core L1544 and the protostellar core HH211
Giers, K., Spezzano, S., Caselli, P., Wirström, E., Sipilä, O., Pineda, J.E., Redaelli, E., Bop, C.T., and Lique, F.
Astronomy & Astrophysics, vol. 676, p. A78 (2023)

Summary: Observations with the 20 m telescope in the frequency range 70-90 GHz has helped determine the deuteration levels in two cores at different stages of development (pre-stellar vs protostellar). Several molecules were observed including ions and radicals along with their deuterated and isotopically substituted species. The main result is that the deuteration levels are similar in the two sources indicating that the pre-stellar values are retained into the protostellar stage and not severely affected by processes during the transition. Since these are cores in two different Milky Way clouds, it is also an indication that differences in initial conditions do not play a major role for the deuteration levels that develop at later stages. (See Fig. 3.7.)

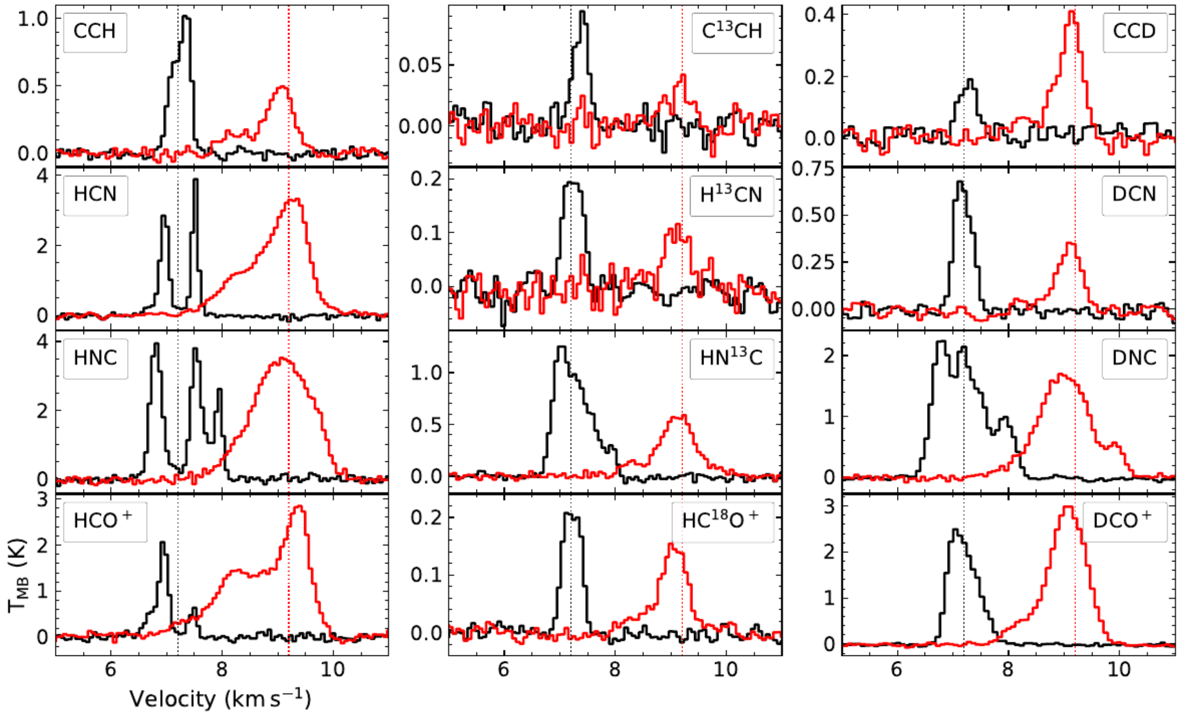


Figure 3.7. *A subset of all lines observed in pre-stellar core L1544 (black) and protostellar core HH211(red) by the OSO 20 m telescope. The vertical lines indicate the systemic velocities of the two sources.*

3.6 Geosciences

[VR grant module 6]

ITRF2020: an augmented reference frame refining the modelling of nonlinear station motions

Altamimi, Z., Rebischung, P., Collilieux, X., Métivier, L., Chanard, K.

Journal of Geodesy, vol. 97, p. 47 (2023)

Summary: This paper describes the newest realization of the International Terrestrial Reference System (ITRS), called ITRF2020. It is a combination of results derived with four space geodetic techniques, Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR) and Doppler Integrated on Satellite (DORIS). The ITRF2020 for the first time in the history of ITRF combinations, achieves a scale agreement between SLR and VLBI at the level of 0.15 ppb, corresponding to 1 mm at the equator, with no drift. This is a clear indication for the stability of the frame and the improvement in consistency between the space geodetic techniques.

Evaluation of the first three years of VGOS 24 h sessions using a Kalman filter with C5++

Diamantidis, P.-K., Haas, R.

Earth, Planets and Space, vol. 75, art. no. 114 (2023)

Summary: This paper discusses the analysis of the first three years of VGOS 24 h sessions. The achieved station position repeatabilities are about 2 mm for the horizontal station position components and better than 4 mm for the vertical station components. For the first time a so-called VGOS-adjusted ICRF3 radio source catalogue is determined, using soft constraints to celestial pole offsets and polar motion in the estimation process. Comparing ICRF with the new VGOS-adjusted ICRF3 shows a stability on the level of 50 µas. Subsequently using the VGOS-adjusted ICRF3 significantly decreases the mean biases that are estimated with respect to the C04-20 EOP series.

A Novel Tropospheric Error Formula for Ground-Based GNSS Interferometric Reflectometry
Feng, P., Haas, R., Elgered, G.
IEEE Transactions on Geoscience and Remote Sensing, vol. 61, p. 1, art. no. 5802918 (2023)

Summary: This paper describes a Novel Interferometric Tropospheric Error (NITE) formula for ground based GNSS interferometric reflectometry. This NITE formula contains two parts: a geometric displacement error that accounts for the reflection point change due to the atmosphere and the earth curvature, and a path delay derived following the definition of the mapping function (with the small curve path effect included). A validation of the new formula is made using raytracing and radiosonde data. The results show that the NITE formula is more accurate than the previous approaches using either bending angle corrections or the mapping function path delay.

3.7 Device physics and Terahertz technology
[VR grant module 8]

Noise Characterization and Modeling of GaN-HEMTs at Cryogenic Temperatures
Mebarki, M. A., Ferrand-Drake Del Castillo, R., Meledin, D., Sundin, E., Thorsell, M., Rorsman, N., Belitsky, V., & Desmaris, V.
IEEE Transactions on Microwave Theory and Techniques, vol. 71 (5), p. 1923 (2023)

Summary: This work is the first model in the literature describing the high-frequency noise behaviour of GaN-based HEMTs at cryogenic temperature using a two-parameter-noise concept. The model shows noise performance close to that obtained using more mature classical technologies. The suggested model, which is based on measured noise figures and scattering parameters, provides the frequency and the bias dependence of the cryogenic noise properties of AlGaN/GaN HEMTs. The model provides a basis for the future design and implementation of GaN-based cryogenic low-noise amplifiers for radio astronomy instrumentation.

4 Instrument upgrades and technical R&D

4.1 ALMA
[VR grant modules 2 and 8]

In this section, we describe contributions to R&D related to ALMA from both the Nordic ARC node and GARD.

The Nordic ARC node:
The Nordic ARC contributed with dedicated personnel to the ESO ALMA Development Study *"High-Cadence Imaging of the Sun"* (PI: S. Wedemeyer & Toribio). The study explores the potential of sub-second ALMA observations of the Sun, and particularly the challenges for the interferometric imaging techniques. The study was completed and accepted by ESO in March 2023.

The project METAsurfaces FOr RAdioastronomy (METAFORA) was approved to be funded by STINT during 2023. The project is an international collaboration between Sweden and Chile aimed at exploring the use of metasurfaces in radio astronomy, in particular for ALMA. The project involves researchers based in Sweden from KTH (Quevedo-Teruel; PI), Lund and Chalmers, including the Onsala Space Observatory (Toribio). The kick-off took place in November 2023. The project will last for two years.

Node staff were also involved in the proposals of two new ESO ALMA Development Studies in the last call for proposals, one of which was accepted in December 2023. The new ESO study is led by Onsala Space Observatory staff (PI: Hess) with the participation of Nordic ARC node members. It will start in 2024 and will provide Advanced Data Products for the ALMA Science Archive.

Node staff also began participation in a project to visualize ALMA polarization data (PI: Vlemmings, Chalmers) accepted in the first open call of the new national infrastructure for data visualization (InfraVis).

GARD:

The ALMA Band 2 project, run by a European Consortium that included partner institutions from the Netherlands (NOVA, Groningen), Italy (INAF, Bolonga), and Sweden, (GARD OSO, Chalmers) achieved impressive results during 2023. The consortium completed the construction of six pre-production ALMA Band 2 receiver cartridges, with a cold cartridge assembly (CCA) designed by GARD and the warm cartridge assembly (WCA) delivered by RPG GmbH. Five of the built pre-production Band 2 receiver assemblies have been accepted for integration within ALMA antennas. At the time of writing two ALMA Band 2 cartridges have been integrated into ALMA Front End (FE) cryostat (see Fig. 4.1) and are undergoing various tests. During summer 2023 these two receivers demonstrated first-light fringe operation as part of ALMA Observatory. GARD assisted the integration of the ALMA Band 2 cartridges by developing and fabricating the highly specialized tools needed for refurbishing an ALMA front-end and adapting it for the installation of ALMA Band 2 CCAs.

Based on the above success the ALMA Board together with ALMA partners took the decision to deploy ALMA Band 2 receivers on all ALMA antennas. To prepare for ALMA Band 2 full production, a Manufacturing Readiness Review meeting was run under ESO supervision with the participation of all ALMA Band 2 Consortium partners. As a result, the proposed design of the CCA (GARD) and WCA was adopted for installation in all ALMA antennas. Band 2 is the last band supplied that completes the initial suite of 10 receiver channels for the ALMA Observatory.

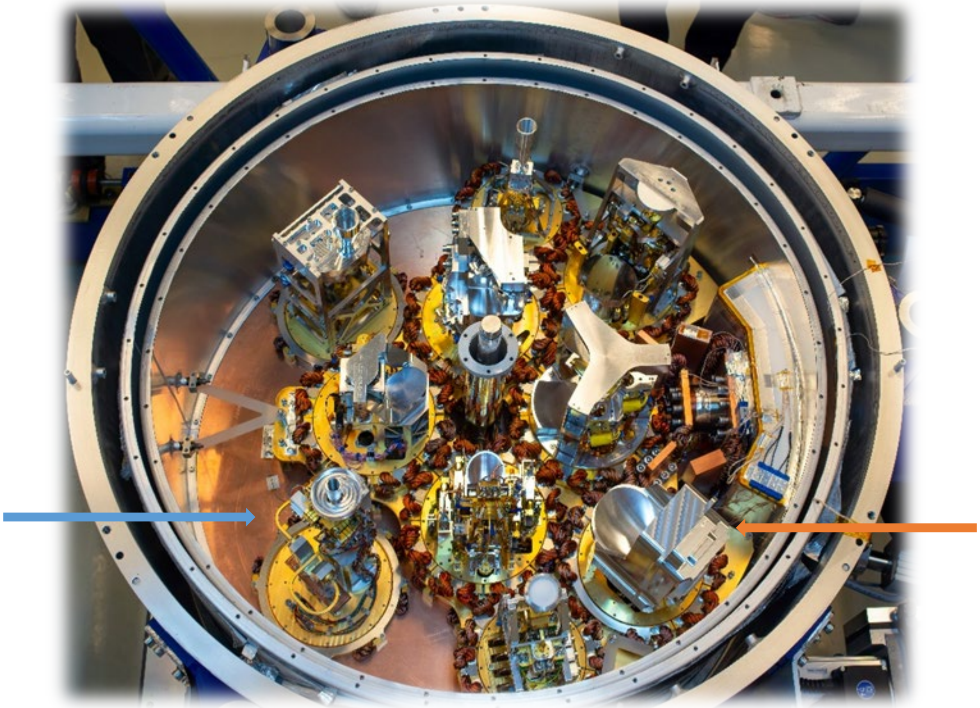


Figure 4.1. *The ALMA Front End cryostat with all ten receiver channels installed. The blue arrow (left) points to newly integrated ALMA Band 2 CCA designed by GARD. The orange arrow (right) points to ALMA Band 5 CCA designed and produced by GARD (in collaboration with NOVA, NL).*

GARD also ran a short project in ESO during the summer 2023 developing a method and hardware to retrofit parts in the few ALMA band 2 receivers already installed in the Front End (FE) without completely opening the FE cryostat. The method was successfully implemented during the summer with the help of ESO.

4.2 APEX

[VR grant modules 3 and 8]

One of the two polarisation channels for the SEPIA660 receiver started to show instabilities of total power measurements during the year. After consultations with NOVA (the mixer supplier), their suggestion was to increase the voltage bias for the affected frequencies, and this removed the instabilities. Their interpretation was that the mixer properties for this channel had changed slowly over time. The implemented change led to a small cost of about 5 K increase of the receiver temperatures for the affected polarization channel.

For the Event Horizon Telescope (EHT) measurement campaign using SEPIA345, GARD developed a fixture with adjustable mounting point for the Tone injector. The fixture was produced by MPIfR and was installed successfully at SEPIA.

4.3 Astronomical VLBI

[VR grant module 4]

In radio astronomy, wider observing bandwidth allow astronomers to image fainter cosmic radio sources. In May 2023, OSO tested its new digital backend DBBC3 further and ran 86-GHz VLBI science observations with a data rate reaching 16 Gbps (dual polarization and 2 GHz per polarization) for the first time. Figure 4.2 shows the correlation amplitude and phase versus time in 32 sub-bands. With such broadband VLBI observations, astronomers obtain double the baseline sensitivity and have a much higher chance to reveal some unprecedented results about distant black hole jets and shadows.

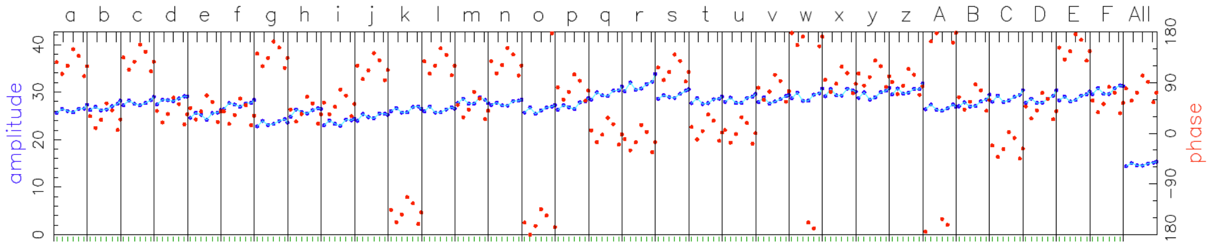


Figure 4.2. *Plots of correlation amplitude (in blue) and phase (in red) versus time in 32 subbands (labelled as a-z and A-F) on the baseline of Onsala to the phased-up NOEMA (North Extended Millimetre Array in France). The NOEMA array consists of 12 individual 15-metre telescopes. In the plots, each point represents an average of 30 seconds and 64 MHz visibility data. The scan lasted about 2 minutes.*

At OSO, we continue to partake in monitoring repeating Fast Radio Bursts (FRBs), both in single dish mode and as part of a VLBI campaign dubbed PRECISE. Initiated as an ad hoc array PRECISE has since inspired the EVN to introduce a new observing mode called EVN-Lite. In this mode, observers can apply for hundreds of hours of EVN observing time outside the regular sessions – under the condition that not all data need to be correlated. The PRECISE-team lead by Franz Kirsten at OSO were the first to get granted an EVN-Lite project which started in February 2023 for a runtime of one year. The project was renewed for another twelve months as of February 2024. During 2023 the PRECISE efforts lead to a publication by Bhandari et al. (2023).

In single dish mode, the Onsala 25 m dish also monitors exceptionally active repeating FRBs in conjunction with the 32 m dish in Torun, Poland, the 25 m RT1 telescope in Westerbork, Netherlands, and the 40 m dish in Stockert, Germany.

4.4 LOFAR

[VR grant module 5]

Technical changes to the Swedish LOFAR station during 2023 were limited to an upgrade of the air-conditioning (A/C) unit to one with a higher cooling power. This upgrade is needed since the coming deployment of LOFAR 2.0 in 2025 will produce more heat in the container.

4.5 The Onsala 20 m telescope

[VR grant modules 4 and 6]

Inspection of the helical 25:1 gearboxes in the 20 m telescope elevation drive train that was made in 2022 showed large amounts of wear leading to unwanted effects in the tracking functions (over-shoots etc). In early 2023 new gearboxes (four) were installed from the same manufacturer as the original ones (from 1976). The new hardware led to increased friction and considerable time had to be spent running the antenna in slewing mode to break-in the new gearboxes. Numerous tests were also conducted to decide on which lubrication agent was best to reduce friction at start-up in cold conditions with eventually the same thin oil used for the OTT being chosen. Finally, a new gearbox heating system had to be installed to bring back the slewing time to switch between sources in geodetic mode to acceptable levels.

On the software side significant upgrades were made to the low-level control system that handles tracking and interfaces directly to the motors (ACAPS). Previously, the communication had to be conducted in a very specific order with precise timing since there was no way to tie a specific response/acknowledgement to the corresponding original query/command sent which has led to faults and unnecessary overhead time over the years. After the upgrade all messages and responses are tagged with unique IDs which allows communication to be done without built-in delays and thus more efficiently. Additionally, unnecessary overheads were removed from the tracking loop by allowing it to be interrupted immediately when a new source command is sent.

4.6 Geoscience

In December 2023 invar systems were installed in the OTT towers, one each, to monitor the temperature induced height variations of the telescopes' reference points.

In May, a new radiometer of the type RPG-HATPRO-G5 was installed. It was baptised Greta (Ground-based Radiometer measuring Emission Temperatures of the Atmosphere). Greta observes the sky brightness temperatures in 14 different frequency bands. Seven channels in the K- and the Ka-band, between 22 and 31 GHz, and seven channels in the V-band, between 51 and 58 GHz. All channels in the K- and Ka-bands have a bandwidth of 230 MHz. In the V-band the channels at the four lower frequencies also have a 230 MHz bandwidth whereas it is significantly larger for the three higher frequency bands. More details on the hardware can be found via the RPG website (www.radiometer-physics.de). Greta operates in parallel to Konrad. During most of the time Greta carries out line-of-sight observations coordinated with the Onsala radio telescopes while they are performing geodetic VLBI experiments. The observation schedule for Konrad is a continuous mapping of the sky above elevation angles of roughly 20 degrees, using cycles of 2 min from 1 January to 22 August. Thereafter, the length of the cycle was increased to 5 min, until the end of the year, resulting in a denser spatial sampling, resulting in many more directions on the sky being observed.

4.7 Development of new millimetre/sub-millimetre devices

[VR grant module 8]

During 2023, GARD run several research and development projects having external, internal and mixed funding that related to advancing technologies, devices, and instruments for radio astronomy and environmental science instrumentation. Additionally, GARD continued work on upgrading and extending facilities for characterization and tests of the devices and instruments. A new 4 K test cryostat with built-in optics for mm-submm receiver testing, hot/cold noise temperature characterization with semi-automatic measurement system was completed and made available for use under 2023. Figure 4.3 shows the interior of the cryostat with the optical system and an SIS mixer installed for testing.

A GARD research project funded by VR that actively continued during 2023 focused on device modelling and noise characterization of AlGaN/GaN HEMT transistors at cryogenic temperatures. This project is a collaboration with the Microtechnology and Nanoscience department at Chalmers investigating the potential use such devices in future radio-astronomy receivers. AlGaN/GaN HEMT technology was shown to deliver promising results, in particular the use of superconducting Nb gate was studied. Some devices show noise temperatures comparable to other semiconductor technologies and further studies aim for the optimization and improvement of the devices.

GARD ran during 2023 several studies targeting the development of ultra-wideband receivers. One project funded by the ESO ALMA upgrade program was dedicated to microfabrication technology development for the new type of superconducting tunnel junctions, SIS, with AlN tunnel barrier. This project achieved very good progress with the fabricated SIS junctions demonstrated over the frequency range 200-380 GHz that covers simultaneously ALMA bands 6 and 7. This mixer is depicted in Fig. 4.3. On top of that, GARD fabricated junctions have been tested in the NOVA ALMA Band 9 receiver and produced very competitive noise performance. As a result, this project is planned to be successfully completed around May 2024. Figure 4.4 (left) shows an example of the current-voltage characteristic of a Nb/Al-AlN/Nb SIS junction with R_nA product of 14 Ohm·μm^2 and area of ca. 2 μm^2 that is part of another ESO funded project that targets a Band 6 and 7 cold cartridge demonstrator for ALMA aiming to explore instantaneous IF bandwidth up to 16 GHz (e.g. frequency range 4-20 GHz). In 2023, the project progressed significantly and a DSB SIS mixer prototype demonstrated competitive performance in the RF band 200-380 GHz with IF bandwidth 4-20 GHz, see Fig. 4.4 (right). As part of this latter project, GARD achieved many interesting results introducing innovative waveguide matched loads that are highly demanded for 2SB mixer technology, including also making an ultra-wideband 3 dB waveguide hybrid that also perform well over the target 210-380 GHz frequency range.

A separate GARD project aimed to introduce a novel technological platform employing microfabricated metal substrates in combination with micro-machined silicon-based substrates to fabricate SIS junctions. These studies performed as a PhD student project led to impressive results and will culminate in PhD thesis disputation by Cristian Daniel López in March 2024.

During 2023, GARD secured funding for two new externally funded projects, EC supported RADIOBLOCKS WP2.2 and an ESO ALMA upgrade program funded project on Advanced Waveguide Components and Technologies.

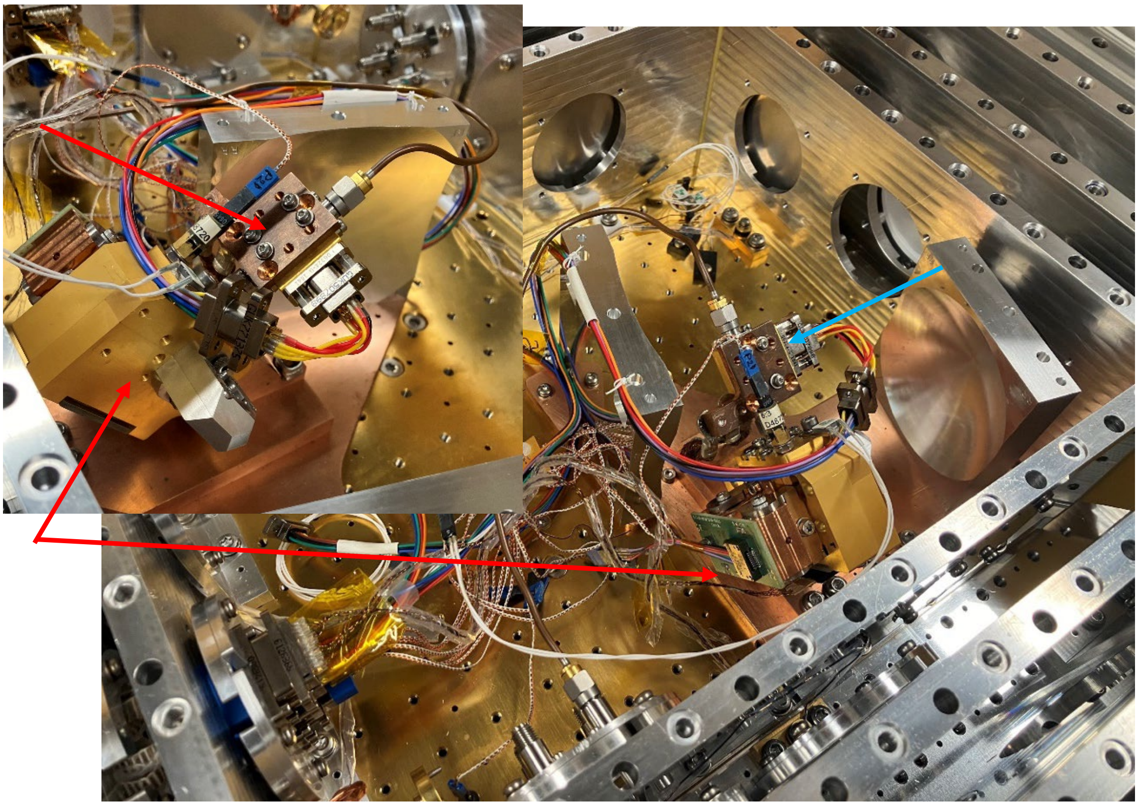


Figure 4.3. *Interior of the GARD built 4K cryostat. The blue arrow indicates the incoming optical signal, in this case between 200 and 400 GHz. The insert shows details of the installed SIS mixer with single red arrow pointing to the 4-20 GHz cryogenic low-noise amplifier and the double arrow pointing at the SIS mixer detailed view (at the insert) and its position at the cryostat, main view.*

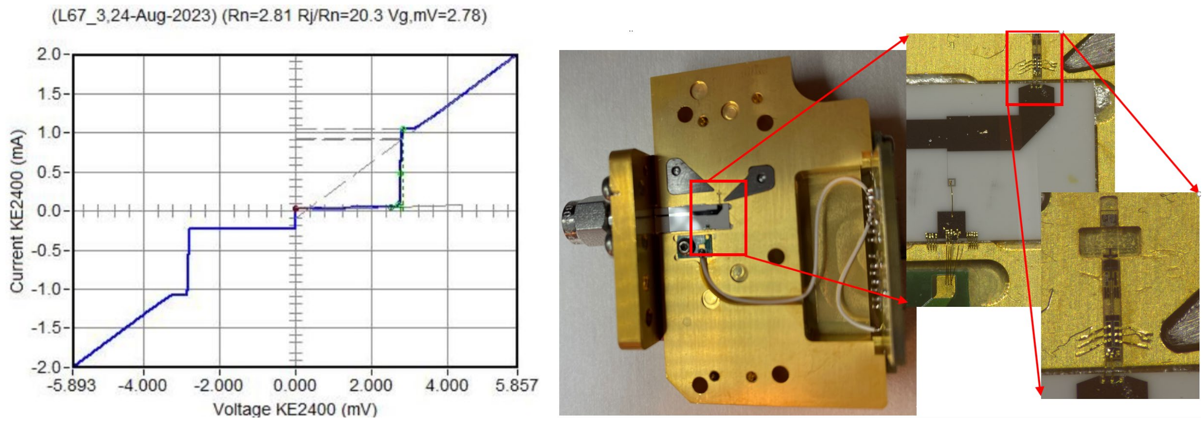


Figure 4.4. *Left: current-voltage characteristic of a Nb/Al-AlN/Nb SIS junction with a RnA product of 14 Ohm·µm² and area of ca 2 µm² that is used within a SIS mixer that is part the GARD ESO funded project that targets developing a Band 6+7 cold cartridge demonstrator. Right: Interior of the GARD built DSB SIS mixer operating in the RF band 200-380 GHz with IF band 4-20 GHz.*

5 SKA – The Square Kilometre Array

[VR grant module 9]

5.1 Introduction

The Square Kilometre Array is the next major step forward in centimetre and metre wave radio astronomy, consisting of two new interferometric arrays with greatly enhanced sensitivity and sky survey speed compared to existing radio telescopes. The part of SKA operating at cm wavelengths (SKA-mid) will be realized in South Africa by adding 133 dishes to the existing 64 dish MeerKAT array. The metre wavelength part (SKA-low) will be built in Australia partly utilizing the infrastructure of the MWA SKA precursor telescope. The global headquarters of the SKA Observatory, that coordinates the development of the whole SKA project, is located at Jodrell Bank in the UK. (See Fig. 5.1.)

Sweden has, since the establishment of the SKAObs Intergovernmental Organization in early 2021, been attending council meetings as an Observer (with Sweden represented by Lars Börjesson from Chalmers and Mathias Hamberg from VR). All the national funding required for Sweden to participate in the SKA construction and operations phase is identified and is committed. Sweden formally participates in the SKA project via means of a bilateral agreement between the SKA Observatory and Chalmers University of Technology. The original bilateral agreement, which otherwise was due to expire in October 2023, was during the summer of 2023 extended till the end of 2024. This bilateral agreement identifies Chalmers as a collaborating organization within the framework of the SKA international convention. This status gives full industrial and scientific rights to Swedish companies and scientists in return for the specified Swedish financial contribution. A formal application for Sweden to join the SKA Observatory as a full member is currently being processed by the Swedish government. A joint communique issued 19 June 2023 on the occasion of a visit by the Swedish prime minister Ulf Kristersson to the UK prime minister Rishi Sunak stated, in the text concerning scientific cooperation, “We welcome Sweden’s intention to become a full member of the Square Kilometre Array Observatory and reaffirm UK support for the European Spallation Source”.

Figure 5.1. *Composite image of the SKA telescopes, blending real hardware already on site with artist's impressions. Left: An artist's impression of the future SKA-Mid dishes blend into the existing precursor MeerKAT telescope dishes in South Africa. Right: An artist's impression of the future SKA-Low stations blends into the existing AAVS2.0 prototype station in Western Australia. Credit: SKA Observatory.*

5.2 Swedish industrial contributions to SKA constructions

Sweden is the "Level 1" lead for two work packages within SKA construction, namely for the SKA-mid Band 1 receiver (covering 350-1050 MHz) and for the SKA-mid Digitizers which convert the analogue signals received at each antenna into digital signals suitable for further processing. Connected to these two areas during 2023 the West Sweden company Omnisys won a large contract worth 12 Million Euros for the delivery of Band 1 with a similar sized contract also awarded to the Gothenburg based company Qamcom for the delivery of SKA1-mid Band 1, 2, 3 Digitizers. In addition to the above contracts a third Swedish company, Low Noise Factory, is working as a supplier of Low Noise Amplifiers for two other SKA-mid receiver bands in addition to Band 1.

5.3 SKA Regional Centre planning

A vital component of the SKA project is a network of SKA Regional Centres (SRC) which will collectively form the permanent data archive and advanced processing layer for SKA data. At computer centres close to the SKA-mid and SKA-low telescopes in South Africa and Australia raw SKA data will be converted into raw Observatory Data Products or ODPs (such as data cubes of radio intensity versus spatial coordinates and frequency) – which will then be transferred to the distributed SRCNet nodes. At these nodes ODPs will be further converted into Advanced Data Products (ADPs) such as catalogues of sources (requiring AI and Machine Learning processing for source identification). Sweden is expected to provide its share of SRC node resources in terms of data storage and computation. During 2023 Sweden fully participated in the international SRC Steering Committee (SRCSC) whose mission is to plan in detail this worldwide SRC network.

The Swedish SRC node is being established as a close collaboration between OSO and the Chalmers e-commons organization, which in turn incorporates the Chalmers C3SE data centre for High Performance Computing (HPC). Three recently recruited permanent employees form the nucleus of the Swedish SRC node (with other domain expertise being added from e-commons employees). Dejan Vitlacil and Franz Kirsten joined the Swedish SRC node core team in late 2022 while in April 2023 Kelley Hess began working as the scientific lead of the Swedish SRC node. During 2023 the Swedish SRC node personnel primarily began working within the international Coral group deploying common “data lake” data storage solutions between SRCNet partners. During the second half of 2023 the Swedish SRC node began planning for the deployment of a SKA Science cloud facility - which will then be further expanded with sufficient compute and fast storage to be the basis of the Swedish contribution to the v0.1 release of SRCNet in early 2025.

6 Computers and networks

[VR grant module 10]

During 2023 the two oldest NAFCI-1 (the NAtional Facility Computer Infrastructure-1 cluster located at Onsala) compute nodes were retired, their compute capacity having been replaced and upgraded by the 64-core node purchased in 2022. Currently NAFCI-1 consists of 4 nodes with a total of 136 cores, 2.8 TB RAM and 530 TB of storage capacity. Primary users of the NAFCI-1 cluster are visitors to the Nordic ARC node who can use NAFCI-1 for processing their data both during their visit and remotely when their visit is over. One specific node consists of 1.5 TB RAM and 48 cores, and this is reserved for larger data sets.

The NAFCI-2 cluster hosted at NAISS-C3SE (NAISS: National Academic Infrastructure for Supercomputing in Sweden; C3SE: Chalmers Centre for Computational Science and Engineering) comprised during 2023 of 5 compute nodes, each having 32 cores and 384 GB RAM, as well as 583 TB of dedicated storage. The oldest of the two storage areas which provides 180 TB was decommissioned at the end of 2023; data and applications stored on this were moved to a new allocation on the shared Cephyr storage system as part of OSO's involvement with Chalmers e-Commons.

During 2023 further tests of 32 Gbps VLBI recording have been undertaken, and a development version of the jive5ab recording software has been installed and evaluated. This version allows for incoming network packets to be processed across multiple CPU cores, whereas previously this had to be done using a single core creating a bottleneck. Tests have shown that now the CPU is no longer limiting the recording rate. This means that 32 Gbps recording is easily attainable with a modest multicore CPU, and indeed with sufficient (likely greater than 70) hard disks 64 Gbps should also be achievable.

The internal high-speed network, consisting of 3x 100 Gbps links between the 20 m building containing the VLBI backends and the computer hall in the Administration building, used for both Astronomy and Geodetic VLBI recording as well as LOFAR has been running without issues after new high-speed fibres were installed in 2022. Spare fibres are available should additional 100 Gbps links be needed between the buildings.

External network connections to OSO presently support the transmission needs of geodetic VLBI (1 Gbit/s), astronomical VLBI (1−4 Gbit/s) and LOFAR (3 Gbit/s). OSO is a fully-fledged node of SUNET with redundant 100 Gbps uplinks out from the observatory to both Gothenburg and Halmstad. Presently OSO rents a pair of 10 Gbit/s fibre connections to SUNET, used for ordinary network traffic, plus a dedicated light path to the Netherlands for transfer of LOFAR and astronomical VLBI data. There is also an option to transmit data in IP format, used for sending data to other stations/correlators.

7 Frequency protection

[VR grant module 10]

On behalf of European radio astronomers, the Committee on Radio Astronomy Frequencies (CRAF) of the European Science Foundation (ESF) coordinates activities to keep the frequency bands used by radio astronomy and space sciences free from interference. CRAF has Member Institutes (radio observatories, national academies, or funding agencies) in 20 countries, sometimes more than one per country. CRAF has a chairperson and a secretary, and it employs a full-time Frequency Manager. Sweden is represented in CRAF via OSO. In addition, OSO also contributes to the expenses of the CRAF Frequency Manager, currently stationed at JIVE, The Netherlands. CRAF represents European Radio astronomy at international meetings where possible threats to radio astronomy occur.

Work in CRAF is divided into several small teams, so-called Work Item (WI) teams, which deal with well-defined topics such as satellite services (including the so-called mega-constellations) or questions of spectrum engineering. Some of the WI teams are active on both International Telecommunication Union Radiocommunication Sector (ITU-R) and European Conference of Postal and Telecommunications Administrations (CEPT) related issues.

CRAF's work during 2023 has been dominated by the final preparations for the WRC-23 and ultimately by WRC-23 itself, which ran from 20 November to 15 December 2023, in Dubai. CRAF members were well represented at the conference. From the core committee eight people participated, including the Swedish representative, as well as two from SKAO. Cooperation with international radio astronomy colleagues was excellent. The Provisional Final Acts of the conference are now available (see Fig. 7.1).

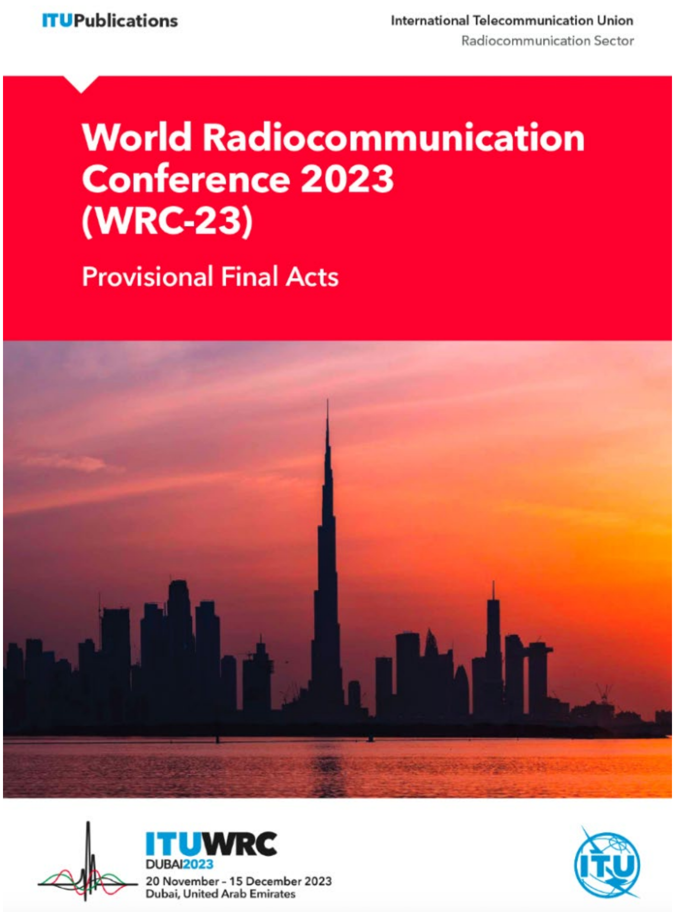


Figure 7.1. *The frontpage of the Provisional Final Acts from WRC-23.*

Prior to the conference, radio astronomers were mostly successful in having methods and options in the Conference Preparatory Meeting (CPM) Report, which would address the protection of the radio astronomy service (RAS). The task at WRC-23 was to ensure that administrations would choose these methods and not the alternatives without RAS protection. During the four weeks of the WRC, CRAF participated in all relevant sessions discussing with all Stakeholders and seeking compromises where necessary. This was successful in almost all cases thanks to the support of many European administrations. However, an International Mobile Telecommunications (IMT) identification in the upper 6 GHz band was made, which may have serious consequences for observations of the methanol line at 6.67 GHz. Still, a small victory, due to the work of CRAF, is that the resolution invites administrations “to take all practical steps to protect the radio astronomy service (RAS) from harmful interference in the frequency band 6650-6675.2 MHz” and invites the ITU-R “to develop an ITU-R Recommendation to address methods for the determination of the protection area around existing RAS stations from IMT stations in the frequency band 6650-6675.2 MHz”. The new ITU-R recommendation will provide some support for administrations looking to protect RAS in this band. Furthermore, it will hopefully allow CRAF to organise at least some level of protection in the harmonised European deployment processes.

The biggest success was the achievement of two new RAS agenda items (AI), in which ITU-R aims to study improved protection of RAS from satellite constellations. This was made possible after extensive advocacy for the Dark and Quiet Skies initiative in African and European countries by colleagues from SARAO/SKAO (South African Radio Astronomy Observatory/Square Kilometre Array Observatory) as well by CRAF. The new AIs will not only investigate technical studies and possible regulatory improvements within the existing ITU-R framework (e.g., the satellite filing processes), but also lays the foundation for a potential recognition of the radio quiet zones protecting SKA-MID and ALMA at the ITU-R, which is essential to extend their applicability to space-borne transmissions.

Another important WRC27 AI concerns the Shielded Zone of the Moon (SZM). 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. Radio astronomy currently enjoys special protection in the SZM. The ITU regulations reserve the spectrum usage in the SZM for radio astronomy and other passive services, with the exemption of active space research and communication with the required research infrastructure. Owing to the increased interest in the Moon and the rejuvenating lunar exploration, both at the scientific and industrial level, spectrum coordination on the Moon has become an important topic at the ITU and elsewhere. With NASA as one of the main proponents, this new AI seeks to add new allocations to the space-research service (SRS) for communication networks on the Moon including its orbit. As the far side of the Moon is highly relevant for astronomy, too, such networks need to be operated with care. Thus, this will be an important AI for CRAF to follow.

As usual, CRAF carried out a lot of other work at European level and in other international groups advocating for Dark and Quiet Skies, including submitting comments to the European Union Commission on a questionnaire regarding a proposed European space law.

The OSO CRAF member, apart from being part of the CRAF Management Team and being involved in the points above, focuses also on interference issues at local and national levels (e.g., via contacts with the Swedish Post- och telestyrelsen, PTS).

8 Memberships of International Committees

During 2023, OSO was represented on the following international boards and coordinating committees. The OSO Infrastructure Director John Conway serves on many of these boards.

- *The European VLBI Network (EVN)* for astronomical VLBI (the Director is a member of the board, and Michael Lindqvist is member of the Programme Committee)
- *The Joint Institute for VLBI ERIC (JIVE),* a European Research Infrastructure Consortium that operates the EVN correlator in Dwingeloo (NL) and supports the EVN activities (the Director is a council member)
- *The International LOFAR Telescope (ILT)* Board, which oversees the operation of the ILT (the Director is a board member)
- *ORP (OPTICON RadioNet Pilot,* an EU-financed Horizon 2020 project which coordinates optical and radio astronomy facilities in Europe (the Director is a board member)
- *SKA Regional Centre Steering Committee* (The Director is a member).
- *SKA communications steering committee* (Robert Cumming is a member)
- *International Astronomical Union Office for Astronomy Outreach* (Robert Cumming is the IAU National Outreach Coordinator for Sweden)
- *International VLBI Service for Geodesy and Astrometry (IVS*), which operates geodetic VLBI (Rüdiger Haas is the chairperson of the IVS Directing board)
- *International Earth Rotation and Reference Frame Service (IERS*) (Rüdiger Haas is a board member)
- *The European VLBI Group for Geodesy and Astrometry (EVGA*) (Rüdiger Haas is Chairman)
- *Inter-Commission Committee on Marine Geodesy (ICCM)* (Rüdiger Haas is an IERS Representative to the Steering Committee)
- *International DORIS Service (IDS)* (Karine Le Bail is member of the IDS Governing Board)
- *The GCOS Reference Upper-Air Network (GRUAN) Global Navigation Satellite Systems (GNSS) precipitable water (GNSS-PW) Task Team (TT)* (Gunnar Elgered is a member)
- *Inter-Commission Committee on Geodesy for Climate Research (ICCC)* (Gunnar Elgered is a member of JWG C.2 Quality control methods for climate applications of geodetic tropospheric parameters)
- *ESF Committee on Radio Astronomy Frequencies (CRAF)* for the protection of the radio band for radio astronomical use (Michael Lindqvist is a member)
- The *Program Committee Effelsberg (PKE)* at Max Planck Institute for Radio Astronomy (Per Bergman is a member evaluating proposals for the Effelsberg 100 m radio telescope)
- *LOFAR Users Committee* (Maria Carmen Toribio is a member)
- *Scientific advisory committee of the International Symposium on Space TeraHertz techniques, ISSTT2024* (Victor Belitsky is a member)

9 EU and ESO projects

[VR grant modules 2, 4, 8 and 9]

During the year, OSO participated in two EU Horizon 2020 and EU Horizon Europe projects: OPTICON RadioNet Pilot (ORP) and Radioblocks. In addition, OSO participated in four projects in ESOs European ALMA development programme.

9.1 OPTICON RadioNet Pilot (ORP) (EU Horizon 2020)

The OPTICON RadioNet Pilot (ORP) project brings together the well-established ground-based astronomy community, to support and develop seamless access to radio and optical facilities in an efficient, co-ordinated and future-looking programme. It offers access to an unrivalled set of major and specialised observatories across Europe (and around the world) covering the optical, infra-red, sub-mm and radio wavebands to open the way to new discoveries. OSO is part of the Transnational Access (TA) program via the European VLBI Network (EVN) and previously, in 2021 and 2022, via APEX.

9.2 Radioblocks (EU Horizon Europe)

The RADIOBLOCKS project takes a holistic view of how radio telescopes arrays capture, process, synthesise and analyse cosmic signals and will develop components, technologies and software, applicable to a wide range of instruments, to enable the next major discoveries in radio astronomy. The project collects the experience and common interests of the radio astronomy community in Europe at large, including several other global parties and industry, all working together to develop the technologies that are necessary for the future evolution of their facilities. GARD is involved in the WP2 working towards wideband SIS mixers towards the goals set by the ALMA Wideband Sensitivity Upgrade (WSU).

9.3 SIS process development to serve next generation receivers for ALMA (ESO European ALMA development programme)

The project focuses on the development at GARD of a stable fabricating process for high-quality small area, $\leq 1\,\mu m^2$ SIS junctions for new generation of receivers for ALMA, to fulfil the requirements of the ALMA WSU. The project is led by GARD and involves NAOJ (Japan) and NOVA (NL).

9.4 ALMA Band 6+7 cold cartridge (ESO European ALMA development programme)

The project aims at the development of critical components for a wideband cryogenic receiver demonstrator to cover 211-373 GHz frequency range (combined ALMA bands 6 and 7) and IF bandwidth up to 16 GHz including cryogenic optics (corrugated feedhorn and cold mirrors); Orthomode Transducer (OMT); SIS mixer chip design optimized for GARD Nb/Al-AlN/Nb junction technology. The project is led by GARD and also involves NOVA (NL).

9.5 Advanced waveguide components and technologies for 2SB dual polarization receiver cartridges (ESO European ALMA development programme)

GARD participates in this ESO project to develop novel technologies and build prototypes of advanced waveguide components and structures for high frequency receivers (ALMA Bands 7 and 9). The project addresses the ambitious WSU (ALMA Wideband Sensitivity Upgrade) goal to improve the sensitivity by minimizing the insertion loss of receiver components, e.g. by developing new microfabrication technologies. The current study will additionally seek improvement of the polarization performance of Bands 7 and 9 by replacing the existing polarization grids by low loss microfabricated orthomode transducers (OMTs). The project is run in collaboration with NOVA (NL).

9.6 High-Cadence Imaging of the Sun (ESO European ALMA development programme)

This project sought to explore the potential of sub-second ALMA observations of the Sun, and particularly address special challenges of interferometric imaging techniques. The Nordic ARC node participated in the project. This study was completed and accepted by ESO in March 2023.

10 Conferences, workshops, schools, etc.

The Nordic ARC node took part in the organization of several schools, conferences, training events and workshops for the ALMA community in 2023:

- The second Meeting of ALMA Young Astronomers (MAYA 2023 conference) was held online 6-10 March 2023. The meeting was well attended by young researchers worldwide with a total of 45 presentations (available online). Node staff were members of the SOC & LOC (co-chair: Muller).
- The ARC node hosted two workshops dedicated to the ALMA Cycle 10 Call for Proposals. The events were in-person and besides the technical aspects of proposals, they included the novelty of presenting writing techniques (Maercker, Chalmers) to help our users in writing successful proposals.
- The ARC node organized a one-day event at the Onsala Space Observatory to commemorate 10 years of ALMA science operations. The event was well attended by our user community (59 participants) and included presentations of the most relevant contributions in the decade from all the research groups, including from the GARD receiver group. The event also served as an occasion to present the ALMA WSU and discuss the current and future needs of our users. Fortunately, the event could also count with a special colloquium by Claudia Cicone (University of Oslo) on the Atacama LArge Submillimetre Telescope (AtLAST), a next generation large single-dish telescope operating in the same frequency bands as ALMA; a future facility project of interest of our user community.
- The continuation of the series of online training events I-TRAIN with the European ARC Network with 3 new events in 2023. Nordic ARC node staff contributed to the coordination of the series and were tutors for the training on the ALMA Single-Dish Pipeline (Tafoya). The series has also an important legacy value, as all trainings are uploaded in the YoutTube channel of the European ARC Network.
- Nordic ARC node staff are SOC members and tutors of the first European ALMA School in Manchester (UK). In 2023 preparations took place for this school which is scheduled for June 2024.

11 Education

The OSO national infrastructure staff are only involved in a minimal way within the academic teaching at Chalmers. The infrastructure does however support teaching by making a small fraction of the time on its telescopes available for exercises by students on Chalmers and other Swedish academic courses. The staff are also sometimes involved in teaching and providing exercises at specialised graduate level schools that are organised from time to time at the Observatory. Specifically, at Chalmers, the 20 m telescope and SALSA (see Fig. 11.1) were used during 2023 in astronomy and physics courses, the 25 m telescope and SALSA in a satellite-communication course, GNSS equipment in a satellite-positioning course, and laboratory equipment in courses on microwave, millimetre wave, and THz technology. Students in the Engineering physics programme at Chalmers visited the Observatory for a half-day, designed as part of the course Experimental physics. Nordic ARC node staff gave a lecture in the course “Data-driven problems in modern astronomy” for PhD students at Chalmers. Students from Stockholm University used the 20 m telescope to learn about radio astronomy.

Figure 11.1. *One of the SALSA antennas in Onsala used for education and outreach, with the radome housing the 20 m telescope in the background. Credit: Magnus Thomasson*

12 Outreach

Outreach activities at OSO are funded by Chalmers and are not part of the national infrastructure’s VR funding. During 2023 we returned to a full programme of guided tours for groups from schools and the public, after the pandemic and the opening during 2022 of our new visitor centre. OSO supported 87 guided tours for schools (all age groups from year 2), civil organisations, companies and groups from Chalmers, receiving in total over 2000 visitors. A further 450 visitors took part in three public events in April (in collaboration with the Gothenburg Science Festival) and in both May and September (in collaboration with Naturum Fjärås Bräcka).

OSO secured a third 1 MSEK grant from the Hasselblad Foundation to cover costs for further development of the centre's exhibition. During 2023 we supervised, implemented and tested a new immersive game, *Where are you in the solar system?*, developed during a masters' project by design engineering students Moa Von Bahr and Ebba Ahlqvist.

We secured joint funding from the International Astronomical Union and the SKA Observatory for a new international pilot project, *Sharing a baseline*. Aimed at school classes (ages 14-15), the project aims to explore ways of connecting school classes with radio observatories and with each other, in five European countries (Sweden, Finland, Italy, the Netherlands and Spain).

Our SALSA telescopes continued to be a popular online resource for students, schools and amateur astronomers.

The Nordic ARC node helped with the ALMA Lego model in the exhibition and gave a presentation about radio astronomy to a school class in Barcelona, Spain.

Staff handled media enquiries on astronomical topics and were regularly quoted in news media.

We communicated news from Onsala facilities and research by Chalmers scientists to the media in collaboration with Chalmers press office and partner organisations, for example the announcement of SKAO contracts for Swedish companies, the deployment of ALMA Band 2, and imaging M87* with the Global Millimetre VLBI Array.

13 Organization

Figure 13.1 shows the organization of the OSO Division, which is the Chalmers organizational entity that hosts the OSO infrastructure (the OSO Division is in turn part of the Chalmers Department of Space, Earth and Environment). The OSO organization is led by a management group containing the OSO Infrastructure Director and Deputy Director, the latter is also head of the OSO Division and has line management responsibilities for all in the Division, plus a Communications officer working on Outreach. The OSO Division has four units, linked to management by solid lines in the organogram, each of which having approximately 10 FTE of personnel.

The Space Geodesy and Geodynamics (SGG) unit manages and runs the OSO infrastructure geoscience measurements. The Observational Support Group consists of astronomy support scientists who manage the OSO astronomy VLBI, APEX and LOFAR observations, staff the Nordic ALMA Regional Centre node, and form the nascent Swedish SKA Regional Centre (SRC) node. The Technical Support Group (TSG) is the core engineering and operations group supporting the OSO astronomy and geoscience observations, with approximately 40%/60% of TSG effort being directed to supporting astronomy and geoscience observations respectively. The infrastructure effort in GARD is directed to APEX receiver support, development of future ALMA receivers, and the development of future Onsala telescope receivers.

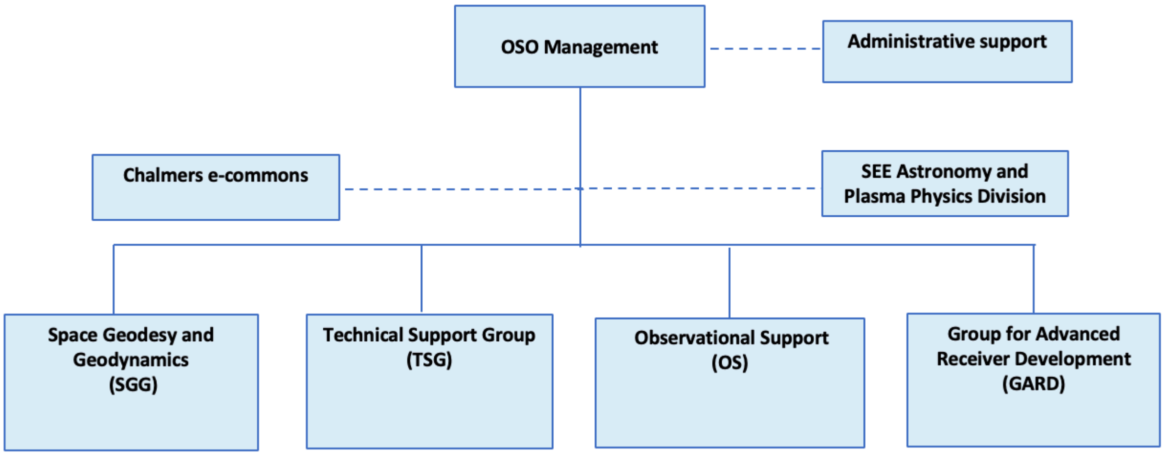


Figure 13.1. *Organogram of Onsala Space Observatory (OSO) infrastructure activity.*

In addition to the above four groups within the OSO Division the OSO Infrastructure makes use of other personnel from outside of the OSO Division as shown by the boxes linked by dashed lines to the management unit. There is approximately 2 FTE dedicated administrative support funded by Chalmers university overhead. There is 0.7 FTE effort bought-in from Chalmers e-commons to support SRC development. Finally, 0.35 FTE of effort is bought in from the Astronomy and Plasma Physics Division of SEE to provide a scientific secretary to the infrastructure (who organizes the OSO Time Allocation Committee, helps in producing Operations group minutes, annual reports and funding proposals etc).

In addition to the internal operational organization of the OSO infrastructure presented in Fig. 13.1 there are two additional bodies that respectively set the long-term strategy of the infrastructure and its detailed scientific programme. The first function is carried out by the OSO Steering committee (OSC), which oversees the OSO infrastructure budget and strategy. In early 2023 one of the OSC's 7 members (Carole Mundell) stepped down and was not replaced during the remainder of the year. The names and affiliations of the current OSC members can be found via the OSO infrastructure website (see the page About us).

The OSO infrastructure scientific programme is in general determined by proposals submitted in response to advertised calls which are evaluated by Time Allocation Committees (TACs) for their feasibility and scientific impact. Many of the observations made by OSO telescopes as part of long baseline interferometer arrays (both traditional VLBI and LOFAR) are allocated by international TACs associated with those telescope networks. Likewise, ALMA observing, which the OSO Nordic ARC node supports, is allocated by an ALMA TAC. OSO has its own Time Allocation Committees (TAC) for allocating Swedish observing time on APEX and for single dish 20 m observing, both of which have one proposal deadline per year (see the Calls for proposals webpage). The pressure on OSO single station LOFAR time is below availability and so instead of having a specific TAC just for this observing mode access is advertised via a Director Discretionary Time (DDT) mechanism in which proposals can be submitted at any time during the year and be evaluated by observatory experts. The same DDT mechanism can be used for scheduling urgent observations on the 20 m telescope or APEX in response to unanticipated events such as a new comet discovery or other transient source.

14 Importance to society

Onsala Space Observatory supports basic research within astronomy and geoscience. Both astronomy and geoscience research have a strong appeal to the curiosity of people of all ages, and this is used in our outreach activities as described above. In addition, geoscience is of importance for understanding the system “Earth”, and therefore of importance for e.g. climate applications, such as monitoring of ozone in the atmosphere and determining changes in the absolute sea level. Geodetic VLBI provides the fundamental terrestrial reference frame which is the basis for all navigational applications. As a by-product of its VLBI activities, the observatory also contributes to establishing the official Swedish time and international time, through two hydrogen maser clocks and one cesium clock. The OSO staff and instruments are also involved in a limited way to education from bachelor to graduate studies at Chalmers, and through organised schools.

15 Importance to industry

During 2023 the major industrial impact of OSO’s work related to the SKA project. The SKA is on such a scale that its components must be provided by industry. The ongoing Swedish involvement in SKA construction will have a large financial payback to Swedish companies. During 2023 Patrik Carlsson of Chalmers Industrial Technology and Big Science Sweden continued to fulfil the Swedish SKA Industrial Liaison Officer (ILO) role. Big Science Sweden (https://www.bigsciencesweden.se) is an organisation which promotes technological and industrial return to Sweden from international Big Science infrastructures. More details of Sweden's industrial involvement in SKA can be found in Sect. 5.2.

Acronyms

A&A	Astronomy & Astrophysics (a scientific journal)
ADP	Advanced Data Products (for SKA)
AG	Absolute gravimeter
AGB	Asymptotic Giant Branch (AGB stars are giant evolved stars)
AI	Artificial Intelligence *or* Agenda Item
ALMA	Atacama Large Millimeter/submillimeter Array (Chile)
APEX	Atacama Pathfinder Experiment (Chile)
ApJ	Astrophysical Journal (a scientific journal)
ARC	ALMA Regional Centre
ASTRON	Netherlands Institute for Radio Astronomy
C3SE	Chalmers Centre for Computational Science and Engineering
CEPT	European Conference of Postal and Telecommunications Administrations
CO	Carbon monoxide (molecule frequently observed by radio telescopes)
CPM	Conference Preparatory Meeting
CRAF	Committee on Radio Astronomy Frequencies (ESF)
DBBC	Digital Base Band Converter (equipment for VLBI observations)
EAS	European Astronomical Society
EC	European Commission
ECC	Electronic Communications Committee
EHT	Event Horizon Telescope
ERIC	European Research Infrastructure Consortium
ESF	European Science Foundation
ESO	European Southern Observatory
EUREF	IAG Reference Frame Sub-Commission for Europe
EVGA	The European VLBI Group for Geodesy and Astrometry
EVN	European VLBI Network
FRB	Fast radio burst
FTE	Full-time equivalent
GARD	Group for Advanced Receiver Development (part of OSO)
GLONASS	Globalnaja navigatsionnaja sputnikovaja sistema
GMVA	Global Millimeter VLBI Array
GNSS	Global Navigational Satellite Systems
GPS	Global Positioning System
GPU	Graphics Processor Unit
GSAC	Galileo Scientific Advisory Committee of the European Space Agency
IAG	The International Association of Geodesy
IAU	International Astronomical Union
ICCC	Inter-Commission Committee on Geodesy for Climate Research
ICCM	Inter-Commission Committee on Marine Geodesy
ICSU	International Council for Science
IERS	International Earth Rotation and Reference Frame Service
IF	Intermediate frequency

IGETS	International Geodynamics and Earth Tide Service
IGS	The International GNSS Service
ILO	Industrial Liaison Officer
ILT	International LOFAR Telescope
IMBH	Intermediate mass black hole
IMT	International Mobile Telecommunications
InSAR	Interferometric synthetic aperture radar
I-TRAIN	Interactive Training in Reduction and Analysis of INterferometric data (activity within the European ARC Network)
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunication Union
IVS	International VLBI Service for Geodesy and Astrometry
JIVE	Joint Institute for VLBI in Europe (NL)
LOFAR	Low Frequency Array
LOFAR4SW	LOFAR for Space Weather (EU Horizon 2020 project)
LoTSS	LOw-Frequency ARray (LOFAR) Two-metre Sky Survey
MINT	Matematik, ingenjörsvetenskap, naturvetenskap och teknikvetenskap (STEM: science, technology, engineering and mathematics)
MNRAS	Monthly Notices of the Royal Astronomical Society (a scientific journal)
MPIfR	Max-Planck-Institut für Radioastronomie
MWA	Murchison Widefield Array
NAFCI	NAtional Facility Computer InfraStructure
NAISS	National Academic Infrastructure for Supercomputing in Sweden
NAOJ	National Astronomical Observatory of Japan
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NOVA	Nederlandse Onderzoekschool Voor Astronomie (The Netherlands Research School for Astronomy)
ODP	Observatory Data Products (SKA)
OMT	Orthomode transducer
ONSA	OSO’s primary GNSS station
ORP	OPTICON RadioNet Pilot (an EU-financed Horizon 2020 project)
OSC	Onsala Space Observatory Steering Committee
OSO	Onsala Space Observatory
OTT	Onsala Twin Telescope
PI	Principal Investigator
RadioNet	Advanced Radio Astronomy in Europe (EU Horizon 2020 project)
RAM	Random-access memory
RAS	Radio astronomy service
RISE	Research Institutes of Sweden
SALSA	Small antennas at OSO for education and outreach

SARAO	South African Radio Astronomy Observatory
SEE	Department of Space, Earth and Environment (OSO’s host department at Chalmers)
SEPIA	Swedish ESO PI receiver for APEX
SEST	Swedish-ESO Submillimetre Telescope (Chile)
SG	Superconducting gravimeter
SIS	Superconductor-isolator-superconductor (a type of mixers)
SKA	Square Kilometre Array
SKAO	Square Kilometre Array Observatory
SLR	Satellite Laser Ranging
SMHI	Sveriges meteorologiska och hydrologiska institut (Swedish Meteorological and Hydrological Institute)
SNR	Signal-to-Noise Ratio
SNSN	Svenska nationella seismiska nätverket
SRC	SKA Regional Centre
SRS	Space-research service
SUNET	Swedish University Computer Network
SWEPOS	The Swedish permanent GNSS network, hosted by Lantmäteriet
SZM	Shielded Zone of the Moon
TAC	Time Allocation Committee
TEC	Total Electron Content
USNO	US Naval Observatory
UT1	The principal form of Universal Time (which is based on Earth’s rotation)
UTC	Coordinated Universal Time (an atomic timescale that approximates UT1)
VGOS	VLBI Geodetic Observing System
VLBI	Very Long Baseline Interferometry
VR	Vetenskapsrådet, The Swedish Research Council
WDS	World Data System, an Interdisciplinary Body of the International Council for Science (ICSU)
WI	Work Item
WP	Work Package
WRC	World Radio Conference
WSU	ALMA Wideband Sensitivity Upgrade
WVR	Water vapour radiometers

Publications 2023

This section lists publications in refereed journals 2023 enabled by the Onsala infrastructure, divided by instrument and separated in two groups: with or without a Swedish author. *For more detailed information about the publication list, see* *Sect. 2.1*. The number of publications per instrument is given below. Two figures are given: total number of publications/number of publications with at least one Swedish author (for ALMA, the first figure is instead the number of papers with at least one Nordic author).

- **ALMA** observations, publications with Nordic authors (119/57) *(Nordic/Swedish)*
  thereof with explicit Nordic ARC node support (20/11) *(Nordic/Swedish)*
- **APEX** observations (all APEX partners' observing time) (49/9) *(total/Swedish)*
- **Astronomical VLBI** obs. w. EHT, EVN or GMVA, or using JIVE (48/17) *(total/Swedish)*
- **LOFAR** observations (124/8) *(total/Swedish)*
- **Geoscience** (OSO instruments specifically stated) (26/7) *(total/Swedish)*
- **Onsala 20 m telescope, single-dish** observations (6/4) *(total/Swedish)*
- **Technical** publications about, e.g., receiver development, by OSO staff (13)

In addition to the publications listed below, in 2023 there were two publications using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), and two publications using data from the Swedish-ESO Submillimetre Telescope *SEST* (closed in 2003).

Note:
- The publications are separated in two groups: with or without a Swedish author.
- In each section, the publications are sorted by first author.
- An excel file with the publications is provided separately.
- For information about the level of ARCnode support for the ALMA publications, see the separate excel file.
- For information about which of the APEX publications are based on observations on Swedish time, see the separate excel file.

Acronyms:

A&A	Astronomy & Astrophysics
Adv. Space Res.	Advances in Space Research
AJ	Astronomical Journal
ApJ	Astrophysical Journal
ApJSS	Astrophysical Journal Supplement Series
ApSS	Astrophysics and Space Science
Exp. Astron.	Experimental Astronomy
Geod. Geodyn.	Geodesy and Geodynamics
IEEE Trans. Antennas Propag.	IEEE Transactions on Antennas and Propagation
IEEE Trans. Geosci. Remote Sens.	IEEE Transactions on Geoscience and Remote Sensing
IEEE Trans. Microw. Theory Techn.	IEEE Transactions on Microwave Theory and Techniques
IEEE Trans. THz Sci. Technol.	IEEE Transactions on Terahertz Science and Technology
J. Astrophys. Astron.	Journal of Astrophysics and Astronomy
J. Geod.	Journal of Geodesy

J. Geo. Res.: Solid Earth	Journal of Geophysical Research: Solid Earth
J. Geophys. Res.: Atmos.	Journal of Geophysical Research: Atmospheres
J. Mol. Spectrosc.	Journal of Molecular Spectroscopy
JSWSC	Journal of Space Weather and Space Climate
MNRAS	Monthly Notices of the Royal Astronomical Society
NatAs	Nature Astronomy
PASA	Publications of the Astronomical Society of Australia
PASJ	Publications of the Astronomical Society of Japan
PSJ	Planetary Science Journal
Phys. Rev. D	Physical Review D
Phys. Status Solidi A	Physica Status Solidi (A) Applications and Materials Science
RASTI	RAS Techniques and Instruments
Remote Sens.	Remote Sensing
Remote Sens. Environ.	Remote Sensing of Environment

ALMA,
publications in refereed journals 2023, with Nordic authors

Swedish authors (ALMA)

MIRI/JWST observations reveal an extremely obscured starburst in the z = 6.9 system SPT0311-58
Álvarez-Márquez, J., Crespo Gómez, A., Colina, L., Neeleman, M., Walter, F., Labiano, A., Pérez-González, P., Bik, A., Noorgaard-Nielsen, H. U., Ostlin, G., Wright, G., Alonso-Herrero, A., Azollini, R., Caputi, K. I., Eckart, A., Le Fèvre, O., García-Marín, M., Greve, T. R., Hjorth, J., Ilbert, O., Kendrew, S., Pye, J. P., Tikkanen, T., Topinka, M., van der Werf, P., Ward, M., van Dishoeck, E. F., Güdel, M., Henning, T., Lagage, P. O., Ray, T., & Waelkens, C.
A&A 671, A105 (2023)
10.1051/0004-6361/202245400

Panning for gold, but finding helium: Discovery of the ultra-stripped supernova SN 2019wxt from gravitational-wave follow-up observations
Agudo, I., Amati, L., An, T., Bauer, F. E., Benetti, S., Bernardini, M. G., Beswick, R., Bhirombhakdi, K., de Boer, T., Branchesi, M., Brennan, S. J., Brocato, E., Caballero-García, M. D., Cappellaro, E., Castro Rodríguez, N., Castro-Tirado, A. J., Chambers, K. C., Chassande-Mottin, E., Chaty, S., Chen, T.-W., Coleiro, A., Covino, S., D'Ammando, F., D'Avanzo, P., D'Elia, V., Fiore, A., Flörs, A., Fraser, M., Frey, S., Frohmaier, C., Fulton, M., Galbany, L., Gall, C., Gao, H., García-Rojas, J., Ghirlanda, G., Giarratana, S., Gillanders, J. H., Giroletti, M., Gompertz, B. P., Gromadzki, M., Heintz, K. E., Hjorth, J., Hu, Y.-D., Huber, M. E., Inkenhaag, A., Izzo, L., Jin, Z. P., Jonker, P. G., Kann, D. A., Kool, E. C., Kotak, R., Leloudas, G., Levan, A. J., Lin, C.-C., Lyman, J. D., Magnier, E. A., Maguire, K., Mandel, I., Marcote, B., Mata Sánchez, D., Mattila, S., Melandri, A., Micha≈Çowski, M. J., Moldon, J., Nicholl, M., Nicuesa Guelbenzu, A., Oates, S. R., Onori, F., Orienti, M., Paladino, R., Paragi, Z., Perez-Torres, M., Pian, E., Pignata, G., Piranomonte, S., Quirola-Vásquez, J., Ragosta, F., Rau, A., Ronchini, S., Rossi, A., Sánchez-Ramírez, R., Salafia, O. S., Schulze, S., Smartt, S. J., Smith, K. W., Sollerman, J., Srivastav, S., Starling, R. L. C., Steeghs, D., Stevance, H. F., Tanvir, N. R., Testa, V., Torres, M. A. P., Valeev, A., Vergani, S. D., Vescovi, D., Wainscost, R., Watson, D., Wiersema, K., Wyrzykowski, Ł., Yang, J., Yang, S., & Young, D. R.
A&A 675, A201 (2023)
10.1051/0004-6361/202244751

ALMA High-frequency Long Baseline Campaign in 2021: Highest Angular Resolution Submillimeter Wave Images for the Carbon-rich Star R Lep
Asaki, Y., Maud, L. T., Francke, H., Nagai, H., Petry, D., Fomalont, E. B., Humphreys, E., Richards, A. M. S., Wong, K. T., Dent, W., Hirota, A., Fernandez, J. M., Takahashi, S., & Hales, A. S.
ApJ 958, 86 (2023)
10.3847/1538-4357/acf619

The ALMA-ALPINE [CII] survey: Kennicutt-Schmidt relation in four massive main-sequence galaxies at z ~ 4.5
Béthermin, M., Accard, C., Guillaume, C., Dessauges-Zavadsky, M., Ibar, E., Cassata, P., Devereaux, T., Faisst, A., Freundlich, J., Jones, G. C., Kraljic, K., Algera, H., Amorín, R. O., Bardelli, S., Boquien, M., Buat, V., Donghia, E., Dubois, Y., Ferrara, A., Fudamoto, Y., Ginolfi, M., Guillard, P., Giavalisco, M., Gruppioni, C., Gururajan, G., Hathi, N., Hayward, C. C., Koekemoer, A. M., Lemaux, B. C., Magdis, G. E., Molina, J., Narayanan, D., Mayer, L., Pozzi, F., Rizzo, F., Romano, M., Tasca, L., Theulé, P., Vergani, D., Vallini, L., Zamorani, G., Zanella, A., & Zucca, E.
A&A 680, L8 (2023)
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Barnes, A. T., Liu, J., Zhang, Q., Tan, J. C., Bigiel, F., Caselli, P., Cosentino, G., Fontani, F., Henshaw, J. D., Jiménez-Serra, I., Kalb, D.-S., Law, C. Y., Longmore, S. N., Parker, R. J., Pineda, J. E., Sánchez-Monge, A., Lim, W., & Wang, K.
A&A 675, A53 (2023)
10.1051/0004-6361/202245668

PHANGS-JWST First Results: Multiwavelength View of Feedback-driven Bubbles (the Phantom Voids) across NGC 628
Barnes, A. T., Watkins, E. J., Meidt, S. E., Kreckel, K., Sormani, M. C., Treß, R. G., Glover, S. C. O., Bigiel, F., Chandar, R., Emsellem, E., Lee, J. C., Leroy, A. K., Sandstrom, K. M., Schinnerer, E., Rosolowsky, E., Belfiore, F., Blanc, G. A., Boquien, M., Brok, J. den ., Cao, Y., Chevance, M., Dale, D. A., Egorov, O. V., Eibensteiner, C., Grasha, K., Groves, B., Hassani, H., Henshaw, J. D., Jeffreson, S., Jiménez-Donaire, M. J., Keller, B. W., Klessen, R. S., Koch, E. W., Kruijssen, J. M. D., Larson, K. L., Li, J., Liu, D., Lopez, L. A., Murphy, E. J., Neumann, L., Pety, J., Pinna, F., Querejeta, M., Renaud, F., Saito, T., Sarbadhicary, S. K., Sardone, A., Smith, R. J., Stuber, S. K., Sun, J., Thilker, D. A., Usero, A., Whitmore, B. C., & Williams, T. G.
ApJ 944, L22 (2023)
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Another X-ray UFO without a momentum-boosted molecular outflow. ALMA CO(1-0) observations of the galaxy pair IRAS 05054+1718
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Eklund, H.
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A ring-like accretion structure in M87 connecting its black hole and jet
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Investigating the hot molecular core, G10.47+0.03: A pit of nitrogen-bearing complex organic molecules
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Non-Nordic author(s) with support from the Nordic ARC node (ALMA)

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APEX,
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Note: *Partly based on APEX publications in the ESO Telescope Bibliography*
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The shocked molecular layer in RCW 120
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Main Sequence to Starburst Transitioning Galaxies: Gamma-Ray Burst Hosts at z ~ 2
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Comparison of Polarized Radiative Transfer Codes Used by the EHT Collaboration
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Extended far-UV emission surrounding asymptotic giant branch stars as seen by GALEX
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Polarimetric Geometric Modeling for mm-VLBI Observations of Black Holes
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Molecular Outgassing in Centaur 29P/Schwassmann-Wachmann 1 during Its Exceptional 2021 Outburst: Coordinated Multiwavelength Observations Using nFLASH at APEX and iSHELL at the NASA-IRTF
Roth, N.X., Milam, S.N., DiSanti, M.A., Villanueva, G.L., Faggi, S., Bonev, B.P., Cordiner, M.A., Remijan, A.J., Bockelée-Morvan, D., Biver, N., Crovisier, J., Lis, D.C., Charnley, S.B., Jehin, E., Wirström, E.S., and McKay, A.J.
PSJ 4, 172 (2023)
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A Search for Pulsars around Sgr A in the First Event Horizon Telescope Data Set*
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ApJ 959, 14 (2023)
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The SOFIA FEEDBACK [CII] Legacy Survey: Rapid molecular cloud dispersal in RCW 79
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An APEX Study of Molecular Outflows in FUor-type Stars
Cruz-Sáenz de Miera, F., Kóspál, Á., Ábrahám, P., Csengeri, T., Fehér, O., Güsten, R., and Henning, T.
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Deep Herschel observations of the 2 Jy sample: assessing the non-thermal and AGN contributions to the far-IR continuum
Dicken, D., Tadhunter, C.N., Nesvadba, N.P.H., Bernhard, E., Könyves, V., Morganti, R., Ramos Almeida, C., and Oosterloo, T.
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Large-scale velocity-coherent filaments in the SEDIGISM survey: Association with spiral arms and the fraction of dense gas
Ge, Y., Wang, K., Duarte-Cabral, A., Pettitt, A.R., Dobbs, C.L., Sánchez-Monge, A., Neralwar, K.R., Urquhart, J.S., Colombo, D., Durán-Camacho, E., Beuther, H., Bronfman, L., Rigby, A.J., Eden, D., Neupane, S., Barnes, P., Henning, T., and Yang, A.Y.
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Protonated hydrogen cyanide as a tracer of pristine molecular gas
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An interferometric SETI observation of Kepler-111 b
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GaN High-Electron-Mobility Transistors with Superconducting Nb Gates for Low-Noise Cryogenic Applications
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ALMA Band 2 Receiver Automated Test System
Barkhof, J., Hesper, R., Realini, S., Bekema, M. E., Koops, A., De Haan, R., Adema, J., Baryshev, A., Rodenhuis, M., Belitsky, V., Fredrixon, M., Lapkin, I., Pavolotski, A., Strandberg, M., Ferm, S.-E., López, C. D., Cuttaia, F., Ricciardi, S., Terenzi, L., Villa, F., Nesti, R., Phillips, N., Yagoubov, P.
Proceedings of the 32nd IEEE International Symposium on Space THz Technology (2023)

ALMA Band 2 Cold Cartridge Assembly Design
Belitsky, V., Lapkin, I., Fredrixon, M., López, C. D., Ferm, S.-E., Pavolotski, A., Strandberg, M., Sundin, E., Desmaris, V., Hesper, R., Adema, J., Barkhof, J., Baryshev, A., Bekema, M. E., Realini, S., Koops, A., De Haan, R., Rodenhuis, M., Cuttaia, F., Nesti, R., Ricciardi, S., Terenzi, L., Villa, F., Gonzalez, A., Kaneko, K., Sakai, R., Imada, H., Kojima, T., Phillips, N., Yagoubov, P.
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Design and Fabrication of All-metal Micromachined Finline Structures for Millimeter and Sub-millimeter Applications
López, C. D., Desmaris, V., Meledin, D., Pavolotski, A., & Belitsky, V.
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A Cryogenic Scalable Small-Signal & Noise Model of GaN HEMTs
Mebarki, M. A., Ferrand-Drake Del Castillo, R., Sundin, E., Meledin, D., Thorsell, M., Rorsman, N., Belitsky, V., & Desmaris, V.
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Comparison of the low noise performance of GaN HEMTs and MIS-HEMTs at cryogenic temperatures
Mebarki, M. A., Ferrand-Drake Del Castillo, R., Sundin, E., Meledin, D., Thorsell, M., Rorsman, N., Belitsky, V., & Desmaris, V.
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SEPIA345: a dual polarization 2SB cartridge receiver for APEX telescope: Design and Performance
Meledin, D., Lapkin, I., Ferm, S.-E., Desmaris, V., Sundin, E., Pavolotski, A., Fredrixon, M., Strandberg, M., Bergman, P., Torstensson, K., Duran, C., Montenegro-Montes, F. M., & Belitsky, V.
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A broadband and dual-polarization single-layer dichroic filter for applications in Sub-THz range
Montofre, D., Lapkin, I., Meledin, D., Desmaris, V., Helldner, L., Fredrixon, M., López, C. D., & Belitsky, V.
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SIS technology development to serve Next Generation receivers for ALMA
Pavolotski, A., Kojima, T., Masui, S., & Belitsky, V.
Proceedings of the 32nd IEEE International Symposium on Space THz Technology (2023)

Key numbers (nyckeltal)

Please see the following pages. An excel file with the same information is provided separately.

Infrastrukturens namn:	OSO
Diarienummer:	2019-00208 (VR), LM 2021/018157 (Lantmäteriet)
Respondent (namn):	John Conway
Respondent (epost):	john.conway@chalmers.se
Respondent (telefon):	031-772 5503
Avser år:	2023

Katergorier av nyckeltal

1 Anställda (enskilda individer eller FTE)
2 Projekt (representerade av en PI)
3 Användare (enskilda individer)
4 Kvantitet av användning
5 Output

1	Anställda vid infrastrukturen	
1.1	*Enskilda individer*	
	Totalt	55
	Astro user support / ARCnode (Modul 2)	10
	APEX svensk tid (Modul 3)	3
	Astronomisk VLBI (Modul 4)	4
	LOFAR (Modul 5)	2
	Geovetenskap (Modul 6)	17
	Utveckling av mm-mottagare (Modul 8)	7
	Utveckling av cm-mottagare (Modul 9)	6
	Ledning (Modul 1)	3
	Övriga tjänster (Modul 10)	3
1.2	*FTE*	
	Totalt	32,9
	Astro user support / ARCnode (Modul 2)	5,8
	APEX svensk tid (Modul 3)	2,3
	Astronomisk VLBI (Modul 4)	2,6
	LOFAR (Modul 5)	0,8
	Geovetenskap (Modul 6)	7,6
	Utveckling av mm-mottagare (Modul 8)	5,9
	Utveckling av cm-mottagare (Modul 9)	4,5
	Ledning (Modul 1)	1,6
	Övriga tjänster (Modul 10)	2,0

Förklaringar till tabell 2, 3 och 4:

ALMA: Tabell 2: Projekt med en nordisk PI. Cycle 9 (observationer oktober 2022 - september 2023). Genomförda = projekt med minst ett levererat dataset.
Tabell 2, forts: DDT-proposaler (DDT = Directors Discretionary Time) är inte medräknade i statistiken här.
Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle 9.
Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal projekt.

APEX: Alla projekt på svensk tid. Sökta projekt för perioderna P111.

Astronomisk VLBI: Alla proposaler inskickade 2023. Alla observationer utförda 2023.

LOFAR: Alla projekt i Cycle 19 och 20 (observationer december 2022 - ongoing).

Alla projekt observerade under aktuell period rapporteras. I undantagsfall är projekten inte avslutade (vilket OSO saknar information om).

För geoverksamheten kan nyckeltal av detta slag inte rapporteras (se aktivitetsrapporten för detaljer). Dock rapporterar vi observationstid med geodetisk VLBI i tabell 4.

Gråmarkerade fält är inte aktuella för OSO.

		a. Alla projekt			b. Typ av hemvist för alla PI						c. Typ av akademisk hemvist för PI (endast akademiska hemvister)		
					Akademisk			Kommersiell	Offentlig	Övriga			
2	Projekt	Totalt	Män	Kvinnor	Totalt	Män	Kvinnor	Totalt	Totalt	Totalt	Chalmers	Annat svenskt lärosäte	Internationell
2.1	*Sökta projekt*												
	Totalt	285			285						62	8	215
	ALMA (projekt med nordisk PI)	105			105						45	8	52
	APEX svensk tid	11			11						11	0	0
	Astronomisk VLBI	100			100						5	0	95
	LOFAR	69			69						1	0	68
2.2	*Genomförda projekt*												
	Totalt	142			142						18	2	122
	ALMA (projekt med nordisk PI)	19			19						7	2	10
	APEX svensk tid	10			10						10	0	0
	Astronomisk VLBI	50			50						1	0	49
	LOFAR	63			63						0	0	63

3	Användare	d. Alla användare			e. Typ av hemvist för alla användare						f. Typ av akademisk hemvist för användare (endast akad. hemvister)		
					Akademisk			Kommersiell	Offentlig	Övriga			
		Totalt	Män	Kvinnor	Totalt	Män	Kvinnor	Totalt	Totalt	Totalt	Chalmers	Annat svenskt lärosäte	Internationell
3.1	*Sökta projekt*												
	Totalt	972			972						77	23	872
	ALMA (nordiska användare, alla projekt)	139			139						43	22	74
	APEX svensk tid	47			47						18	1	28
	Astronomisk VLBI	449			449						11	0	438
	LOFAR	337			337						5	0	332
3.2	*Genomförda projekt*												
	Totalt	783			783						57	9	717
	ALMA (nordiska användare, alla projekt)	72			72						24	8	40
	APEX svensk tid	52			52						23	1	28
	Astronomisk VLBI	340			340						7	0	333
	LOFAR	319			319						3	0	316

4	Typ och kvantitet av tillgång	g. Total kvantitet per typ av tillgång till infrastrukturen			h. Kvantitet av tillgång för akademiska projekt		
		Alla användare			Fysisk tillgång till infrastruktur		
		Fysisk	Data	Prover	Totalt	Män	Kvinnor
4.1	*Användning under året*						
	Totalt	n/a			n/a		
	ALMA (antal projekt med nordisk PI)	19	17936 GB		19		
	APEX svensk tid (h)	198	2769 records		198		
	Astronomisk VLBI (h)	1086	896/10.1 Tb		1086		
	LOFAR (h)	5413	6.13/2.0 Pb		5413		
	Geodetisk VLBI (h)	3124			3124		

5	Output	
5.1	Publikationer	Se bifogad lista
5.2	Patent	n/a