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Report on the activities in 2021 of

Onsala Space Observatory

The Swedish National Infrastructure for Radio Astronomy

This report presents the activities at Onsala Space Observatory (OSO) during 2021, including the usage of the instruments for scientific purposes, according to the “särskilda villkor” in the contract for operation of OSO between the Swedish Research Council (VR) and Chalmers. The report includes the geoscience activities at OSO, according to the contract with Lantmäteriet.

Artist's impression of a view from a common envelope system in which two stars have just started to share the same atmosphere. Such systems were observed with ALMA by Khouri et al. (2021). Credit: Danielle Futselaar, artsource.nl.

Onsala, 31st March 2022

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Contents

This report is divided into the following sections. The sections or subsections contain (where relevant) a reference to the corresponding modules defined in OSO's March 2017 infrastructure proposal to VR. The geoscience activities, financed by Lantmäteriet, corresponds to module 6. A financial account is provided separately to VR.

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Acronyms
Publications 2021
Key numbers (nyckeltal)

1 Operations

During 2021 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 latter is funded by Chalmers-only sources).
- 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
- 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 (WVRs) to support space geodesy
- The Onsala aeronomy station for observations of H_2O, CO, and O_3 in the middle atmosphere (funded by Chalmers only)
- 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), resp.

1.1 Telescopes

[Modules 3, 4 and 5]

Below we describe the activities of the Onsala telescopes during 2021.

Onsala 20 m telescope: The 20 m telescope was used according to expected plans during 2021. It participated in 43 geodetic 24-hour campaigns, 10 astronomical single-dish projects, 5 extended astronomical VLBI sessions (plus one short out-of-session campaign), 10 24-hours astronomical eVLBI sessions, several extended geodetic test runs in synchronisation with the Onsala Twin Telescopes, 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. There was however a brief interruption for technical trouble-shooting related to a telescope control problem in September which meant that 3 geodetic campaigns were not carried out. The problem was largely resolved at a later time after considerable effort was spent that did not however affect the science observation schedule further. It should be noted that while no major technical upgrade was done for the 20 m telescope in 2021, the aforementioned trouble-shooting necessitated a thorough inspection and evaluation of the software and mechanical parts of the control system which should prove highly beneficial in the future. The most important upgrade was related to safety and safety procedures, e.g., a new barrier has been installed in a location that previously presented a falling hazard for personnel needing to crawl under the cabin, directly above the azimuth axis, to access the motor wells.

Figure 1.1. *The radome with the 20 m telescope in Onsala. Credit: Magnus Thomasson*

Onsala 25 m telescope: The Onsala 25 m telescope was used for astronomical VLBI as planned without any major problems during the year.

Onsala Twin Telescope (OTT): In 2021, The OTT was used for 54 VGOS sessions of different kinds, for a total observing time of approximately 721 hours. See Sect. 1.3 for details.

APEX: Swedish APEX observations, during 2021, were conducted on 28 days (close to the normal number of days, despite the ongoing pandemic), organized mainly in three major observing runs in May, July, and September. To perform service mode observations, OSO normally sends an observing team to Chile for every run. In 2021 no travelling to Chile was possible, and all observations had to be performed remotely from Sweden with local support at APEX. The SEPIA 345 GHz receiver, as well as the nFLASH 230 and 460 GHz receivers, were all accepted as APEX facility receivers in May 2021.

LOFAR: The Onsala LOFAR station operates in two main modes: International LOFAR Telescope (ILT) mode and Local mode. In ILT mode, the station is controlled centrally by ASTRON in the Netherlands. In Local mode the station is controlled by OSO; this observing time is partially allocated via an Onsala open Call-for-Proposals basis and partially via ILT Call-for-Proposals that run in Local mode. In both cases the Local mode time is devoted to pulsar research.

VLBI: Very Long Baseline Interferometry observations were conducted using the Onsala 25 m and 20 m telescopes, and 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 theses 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: 32 days of astronomical VLBI
42 days of geodetic VLBI
95 days of single-dish astronomy

– The Onsala 25 m telescope: 55 days of regular astronomical VLBI
(in addition, observations were carried out on 159 days for the VLBI-campaign PRECISE and magnetar monitoring, see Sect. 4.3)

– The Onsala Twin Telescope: 54 sessions of geodetic VLBI (for details, see Sect. 1.3)

– The APEX telescope: 28 days of single-dish astronomy on Swedish time

– The LOFAR station: 278 days ILT, 74 days Local, out of 352 days observing
(79% ILT, 21% Local)

Note that time for "normal" technical service, pointing, etc. are not included in the above figures. These service activities amounted to about 18 and 10 days on the 20 m and 25 m telescopes, respectively.

1.2 Nordic ARC node

[Module 2]

Nordic ARC node operations in the year 2021 were affected by the developments of the COVID-19 pandemic. Our node operations in 2021 strengthened the full support in using the ALMA telescope provided remotely by our staff to the community of astronomers in the Nordic region.

The pandemic interrupted ALMA operations in 2020: ALMA Cycle 7 operations were suspended, and the Cycle 8 Call for Proposals was also cancelled. Overall, the spread of COVID-19 infection prevented ALMA observations for the period of approximately one year. In March 2021, and thanks to the big efforts carried out by the Joint ALMA Observatory (JAO) regarding safety operations on site, ALMA went back to sky and resumed science observations. In practice, despite such a long disruption and some other shorter suspensions in 2021, the situation allowed to safely resume the same Cycle 7 configuration schedule and planning where it had been stopped but shifted one year. Accordingly, a new Call for Proposals was opened in the spring and Cycle 7 duration was extended to September 2021. To reflect that one-year shift, Cycle 8 was renamed Cycle 8 2021. In this manner, any significant disruptions in the typical duration of the ALMA cycle were minimized both for the telescope operations and the user community in the years to come. The new Cycle 8 2021 could be framed under the standard ALMA Cycle timeline (i.e., Call for proposals in the spring, and regular Cycle operations from October 1st to September 31st, 2022) without having long lasting consequences for the cycles to come.

During the full year of 2021, despite the circumstances, the Nordic ARC staff provided computing resources and a significant amount of support in the form of 14 virtual one-to-one visits of researchers based in Sweden for the analysis of their ALMA data. Besides providing tailored proposal technical support and advice to a dozen researchers, the Nordic ARC provided broad support for the Cycle 8 2021 Call for Proposals in the form of a series of four online events to inform and support the community, covering from an introduction to interferometry and ALMA for newcomers to the relevant new aspects and capabilities to consider in the new cycle, like the dual-anonymous policy and distributed peer review of proposals. Cycle 8 2021 was the first ALMA call in which dual-anonymous and distributed peer-review was implemented in the main call. That was a significant change for the community and dedicated communication efforts were carried out in our Nordic ARC proposal preparation events and during the European ARC Network Community Assembly, as well as with plenty of new documentation and interactions with the ALMA Proposal Handling Team.

Nordic ARC staff were also heavily involved in more direct ALMA operations activities. Significant efforts were directed to assess the quality of the data produced by the telescope before handling it to the PIs. Most of the data reduction of PI observations in 2021 was done through the ALMA Science Pipeline. Our staff conducted the quality assessment of the calibration and products of 32 observation units of Nordic projects. It also intervened by carrying out manual imaging for a handful of non-standard projects that could not be handled by the automatic pipeline, including data recorded in full polarization.

Under the umbrella of ALMA operations, our staff also performs the role of Contact Scientist of accepted projects for Nordic PIs, which in Cycle 8 2021 consisted of 22 projects for the main call and 5 projects in the Supplemental Call. Node staff, in collaboration with the Dutch ARC node (Allegro) and support from JAO, developed an automatic notification system for Contact Scientists within the network to receive periodic reports on the status of PI observations and dynamic information on the configuration of the array. These reports have become an especially useful tool to monitor the life cycle of projects.

To expand the knowledge of our users on interferometry and ALMA, the Nordic ARC node coordinated the series of online training events entitled I-TRAIN with the European ARC Network, which is a regular series of *Interactive Training in Reduction and Analysis of INterferometric data*. In 2021 a total of 9 online trainings were hosted featuring European ARC Network experts and software tools. Besides coordination, the Nordic ARC hosted 8 of the events and provided tutors for 4 of them. The live sessions were well attended, with an average number of ~40 participants. The series has also an important legacy value, as all trainings are uploaded in the YouTube channel of the European ARC Network. It is also worth to highlight the series of short (~3 min) videos ALMA Explained that was released in YouTube by the European ARC Network with the aim of explaining ALMA and basic interferometric principles to non-experts. Nordic ARC staff produced a video on the Fourier Transform and contributed to a second video on polarization observations with ALMA. The node also provided support and computing resources for tutors and participants in the sub-mm stellar evolution hands-on sessions lead by Chalmers tutors during the Virtual OPTICON Archival School using ESO and ALMA data.

To reach out the broad community of ALMA users in Europe, an issue of utmost importance during the pandemic, the branding and launching of European ARC Network social media channels was carried out. Nordic ARC staff has contributed significantly to these efforts in 2021. Thanks to that initiative the network opened Facebook and Twitter accounts and the useful YouTube channel mentioned above. At the Nordic ARC area of influence, we continued our efforts to keep our users informed through our mailing list (86 subscribers). These efforts were complemented with the creation of the Network visibility Working Group, with members of all the ARC nodes, aiming at improving the visibility of the network and its activities among ALMA users in Europe. Among other internal activities within the European ARC Network, the node participated in the yearly All-hands meeting (hosted virtually in 2021).

Among our software tools, efforts were directed to the most popular tools UVMultiFit and POLSIMULATE. For UVMultiFit a dedicated I-TRAIN session was hosted in February 2021 (~85 attendees) and efforts were put into migrating its code to CASA 6 in Python 3. Moreover, all code for our Nordic software tools was migrated to our public repository in GitHub, to facilitate their access and further maintenance and development. Our software developer has put efforts into providing stable installation-packages for the different operating systems and CASA versions.

In 2021 further progress was also made within the European ARC Network project *High-level Data Products in the ALMA Science Archive.* With the goal of adding value to the existing public data in the ALMA Science Archive, node staff advanced in the generation of extra imaging products for projects observed by ALMA in full polarization. Final products are expected to become available to the community in 2022.

In this period, the Nordic ARC has also continued providing support for the ALMA Development Study "High-Cadence Imaging of the Sun" (PI: S. Wedemeyer). A dedicated contribution in the form of sustained support to this project by our node staff was agreed upon for the second half of 2021 until the end of the study in 2022.

Nordic ARC staff (nominal 3.1 FTE in total) have remained stable during this period at a level below optimum, in particular since staff diverted activities towards the involvement of Sweden in the future SKA. Unfortunately, recruitment in general has not been possible due to the Chalmers hiring freeze in place since January 2020, which has prevented the hiring of new personnel in the OSO Observational Support group and ARC node in 2021.

1.3 Geophysical instruments

[Module 6]

Geodetic VLBI:

The geodetic VLBI observing sessions 2021, using the 20 m telescope with its S/X receiver system, were 24 h long and included regular IVS sessions in the R1-, RD-, RV-, T2-series. In total 42 sessions in the IVS program were observed during 2021. 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 for 29 international broadband VGOS operational (VO) sessions of 24 h duration each, and 25 VGOS-B/C (VB) sessions of 1 h duration. During all these sessions both OE and OW were used in parallel and all data were recorded with the corresponding DBBC3 backends in vdif-format on dedicated FlexBuff recorders. While the international VO-sessions were observed in networks of up to 9 VGOS partner stations in total, the VB-sessions were observed together on one baseline with station Ishioka in Japan.

The VO-sessions were correlated at the correlators at MIT/Haystack, MPIfR Bonn, Vienna, and Shanghai. The VB-sessions were correlated at the Onsala correlator. The goal of the VB-sessions is to determine UT1-UTC parallel to simultaneously observed IVS-Intensive sessions with legacy S/X systems and to test the limits of VGOS slewing and recording modes.

Additionally, during 2021 thirteen local interferometry sessions were observed using the On-Oe-Ow cluster, with the goal to connect the twin telescopes to the 20 m telescope. These so-called ONTIE-sessions were all planned, scheduled, observed, correlated, fringe-fitted, and analysed at Onsala.

About 100 short (20 min) flux-monitoring sessions were performed with the OTT interferometer in 2021.

For the other geoscience facilities, the activities are summarised as follows:

GNSS stations:

OSO's primary GNSS station, called ONSA, has operated continuously during 2021. 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 the same networks network. In addition to ONSA and ONS1, the six GNSS stations close to the Onsala twin telescopes were all running 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. The laboratories primary instrument is a superconducting gravimeter (SCG, 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 SCG around the world. In 2021 OSG054 has recorded data over 365 days at 1 Hz sampling rate (no missing data). There was one AG campaign from 15–17 June 2021, performed by Andreas

Engfeld (Lantmäteriet), used for the yearly evaluation of the calibration factor of the SCG. As part of the regular maintenance, the cold head was changed on 30 September 2021, after which unexpected noise was observed at low frequency (around 0.02 Hz). All tested pointed toward a cold head problem. As a result, the cold head was replaced on 17 October 2021 by the one previously in service, until the end of 2021.

Tide gauges:
The Onsala tide gauge station ran uninterrupted for the entire year, excluding the yearly cleaning of the well, and a sensor calibration campaign, when we artificially controlled the sea level in the well, causing a data gap of less than 6 hours on the 6th of July. A second data gap of 2 h occurred on the 27th of August when new nozzles for the pneumatic sensors were installed. The sea level observations are available from the official web site of national sea level data operated by Swedish Meteorological and Hydrological Institute (SMHI). 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 two water vapour radiometers (WVR), Astrid and Konrad, are designed to measure the sky brightness temperatures at 21 GHz and 31 GHz from which the radio wave propagation delay in the atmosphere can be inferred. During 2021 only Konrad was operating more or less continuously from 1st of April to 30th of September. In last year's report we mentioned problems with gain jumps. These were identified to be caused by a slightly broken waveguide which was repaired while the WVR was in the electronic lab during the first 3 months of 2021. Starting in October, maintenance was carried out until the 12th of January 2022. An unstable power supply was replaced as well as the more than 10 years old control and data acquisition computer.

Figure 1.2. *The water vapour radiometer Konrad and othe geoscience instruments in Onsala, with the twin telescopes and the 25 m telescope in the background. Credit: Magnus Thomasson*

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 2021 both radiometers operated without problems, which means that we have about 320 days of collected H_2O and about 330 days of collected CO/O_3 measurements.

Seismometer station:
OSO hosts a seismograph station 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, necessary for VLBI observations, but which also contributes to the universal atomic time. OSO also collaborates with RISE (Research Institutes of Sweden) on a 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 provide redundancy of 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 us by Lantmäteriet, were permanently installed on bedrock at the observatory. The first one (for ascending satellite passes was installed on the 1st of June. The second on (for descending satellite passes) was installed on the 10th of September.

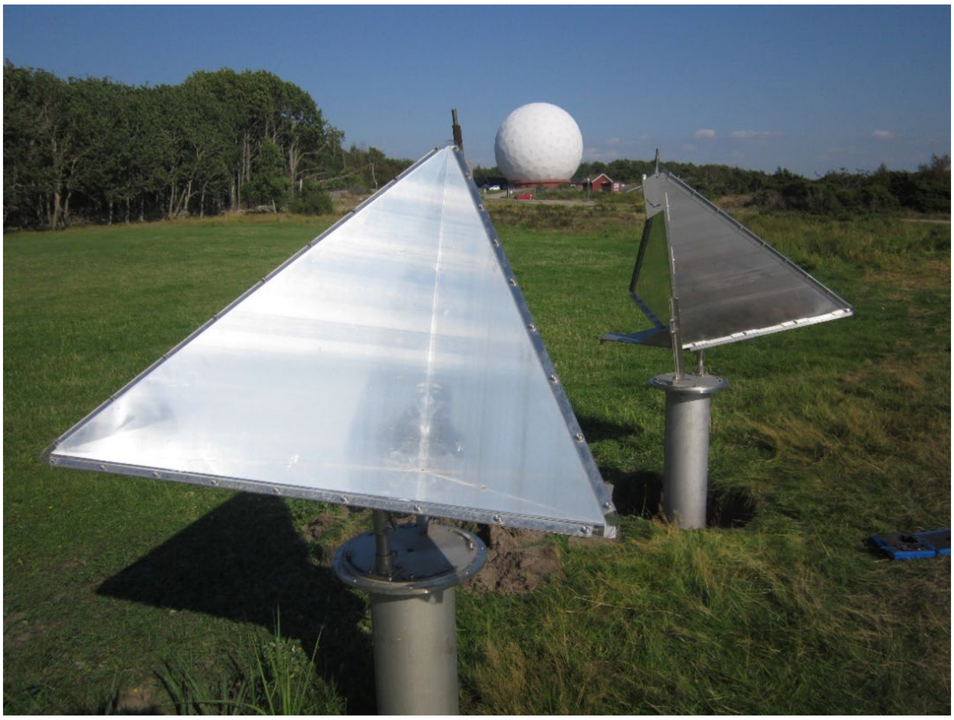

Figure 1.3. *The Onsala TwInSAR reflectors installed in 2021, with the radome housing the 20 m telescope in the background. Credit: Rüdiger Haas*

2 Key numbers

2.1 Astronomy

[Modules 2, 3, 4, 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 7; that is for observations in the period October 2019 – September 2021 (Cycle 7 was extended due to the pandemic). 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, about one quarter of the Swedish users (individuals) were from other institutions than Chalmers. The Swedish non-Chalmers users were affiliated with Stockholm University, Royal Institute of Technology, and Uppsala University.

About one quarter of the users in 2021 were women. There was only a small difference in success rate (fraction of applications for telescope time which are observed) between men and women.

All users did research in the subject area *103 Physical Sciences*.

Number of refereed scientific papers

The associated excel file gives a list for each instrument of *papers in refereed journals published in 2021* (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 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 ALMA the first number 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 raw numbers for ALMA publications below, on the same 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 the number of papers receiving Nordic ARC support is smaller than the total number of ALMA papers authored by Nordic/Swedish is that ~2/3 of those publications used ALMA data from projects that were not lead by Nordic PIs, and therefore received support from other ALMA Regional Centers.

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

• ALMA	90/65, Nordic ARC node dedicated support 30/26	*(Nordic/Swedish)*
• APEX	62/15	*(total/Swedish)*
• Astronomical VLBI	39/13	*(total/Swedish)*
• LOFAR	124/9	*(total/Swedish)*
• 20 m telescope, single-dish	5/3	*(total/Swedish)*
• Technical publ. by OSO staff	9	

In addition, in 2021 there was one publication using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), and 7 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 supported by VR (but by Chalmers funding) and key numbers for them are therefore not given in the tables at the end of this report. We note that in 2021, there were proposals for 10 projects, out of which 9 were observed, plus one from a previous proposal cycle. There were 12 female and 20 male users on the observed projects. Of these, 17 were Swedish (15 of them from Chalmers). In addition, the 20 m telescope was used for observations of Fast Radio Bursts.

2.2 Geosciences

[Module 6]

Users of the geoscience research infrastructure

The OSO geoscience instruments, including the geodetic VLBI observations as the major 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 data and derived products such as station positions, Earth's orientation/rotation rate and gravity field are then 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. As far as we know, all use of the data for scientific purposes was within the subject area *105 Earth and Related Environmental Sciences.*

Number of refereed scientific papers

We have identified 10 papers with one or more Swedish authors and 19 papers with non-Swedish authors published during 2021 where the use of data or services from OSO are specifically stated. 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. A publication list is found at the end of this report. 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 of 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 42 experiments, each one with a length of 24 h and rather evenly spread over the year, were carried out during 2021 with the Onsala 20 m telescope. Additionally, we have been observing with the Onsala twin telescopes during several VGOS sessions; 29 international 24 h sessions and 25 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 in order to guarantee that operation critical information, in particular Earth orientation parameters from VLBI observations, are available for satellite operators, space agencies, and other stakeholders. These databases are fundamental for many scientific disciplines with 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 2021 the GNSS station OSOI has been operated and contributed to ESA's ionospheric monitor network.

Gravimeter Laboratory:

Gravimeter data with one-second samples and maximum with a two-minutes latency is 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", i.e. cleaned from earthquake signatures. IGETS is a service under the auspices of the International Association of Geodesy (IAG). During 2021 one visit with an absolute gravimeter, Lantmäteriet's FG5, took place.

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). Being endorsed by the IERS, its main purpose is 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 a large number of 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 super tide gauge are transferred to SMHI in near-real time. These are available to the public through the SMHI web pages.

Aeronomy station:
During 2021 OSO collected about 320 days of H_2O data derived from its aeronomy station. 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). During 2021 OSO has collected 330 days of CO/O_3 data.

3 Selected scientific highlights

Below follows a list of scientific highlights selected to illustrate the different instruments and science areas covered by OSO. In the listed publications Swedish authors are shown underlined.

Astronomy

Especially highlighted in this section are papers from Swedish astronomers using OSO telescopes or receiving user support provided at OSO (via for instance by the Nordic ARC Node). In addition, some interesting international results that make use of OSO telescopes and/or instrumentation are listed.

3.1 ALMA
[Module 2]

CON-quest: Searching for the most obscured galaxy nuclei
N. Falstad, S. Aalto, S. König, K. Onishi, S. Muller, M. Gorski, M. Sato, F. Stanley, F. Combes, E. González-Alfonso, J. G. Mangum, A. S. Evans, L. Barcos-Muñoz G. C. Privon, S. T. Linden, T. Díaz-Santos, S. Martín, K. Sakamoto, N. Harada, G. A. Fuller, J. S. Gallagher, P. P. van der Werf, S. Viti, T. R. Greve, S. García-Burillo, C. Henkel, M. Imanishi, T. Izumi, Y. Nishimura, C. Ricci and S. Mühle
Astronomy & Astrophysics, volume 649, page A105 (2021)

Summary: Some ultraluminous and luminous infrared galaxies ((U)LIRGs) host compact ($r < 100$ pc), obscured nuclei - called CONs. These objects are highly extincted by large column densities of gas and dust, and as a result are hard to detect at many wavelengths. The intense infrared radiation arising from warm dust in these sources is prone to excite vibrational levels of molecules such as HCN (HCN-vib). The brightest emission of HCN-vib thus far is found in CONs. Thus, Falstad et al. used HCN-vib (3-2) observations of 46 local LIRGs and ULIRGs with ALMA to find out how common CONs are, and whether their commonness depends on the luminosity or other properties of the host galaxy (see Fig. 3.1). As a result of this CON-quest project, Falstad et al. find that in the local Universe 20-40% of LIRGs (ESO320-G030, pictured, is one) and ULIRGs host CONs. These nuclei likely hide a phase of rapid nuclear growth - a star formation burst, or black hole accretion. Many (U)LIRGs hosting CONs show signatures of molecular inflows seen in the far-infrared, and submillimeter observations also reveal compact, often collimated, outflows.

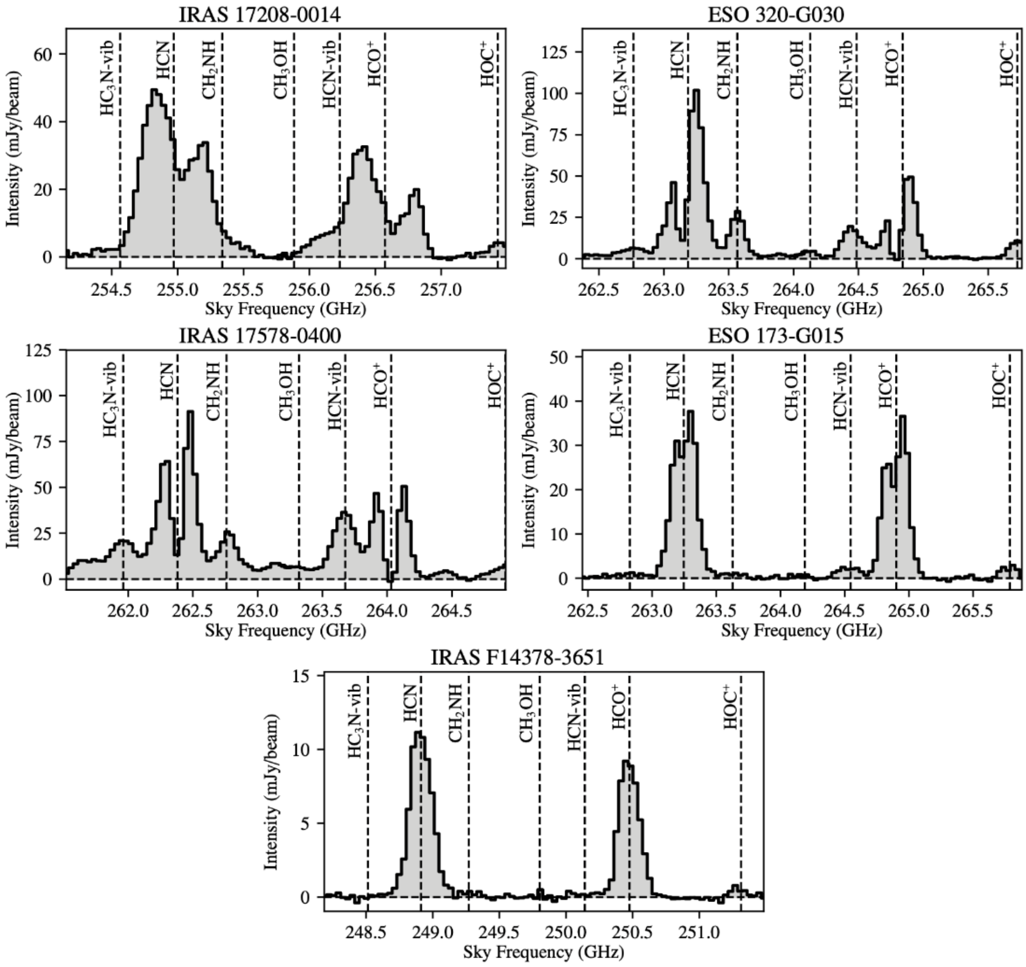

Figure 3.1. *Continuum subtracted central spectra of galaxies with new HCN-vib J = 3−2 detections. Frequencies of some lines commonly seen in CONs are denoted with vertical dashed lines. In many of the sources, the ground-state HCN and HCO^+ transitions are self-absorbed.*

ALCHEMI, an ALMA Comprehensive High-resolution Extragalactic Molecular Inventory

S. Martin, J. G. Mangum, N. Harada, F. Costagliola, K. Sakamoto, S. Muller, R. Aladro, K. Tanaka, Y. Yoshimura, K. Nakanishi, R. Herrero-Illana, S. Mühle, S. Aalto, E. Behrens, L. Colzi, K. L. Emig, G. A. Fuller, S. Garcia-Burillo, T. R. Greve, C. Henkel, J. Holdship, P. Humire, L. Hunt, T. Izumi, K. Kohno, S. König, D. S. Meier, T. Nakajima, Y. Nishimura, M. Padovani, V. M. Rivilla, S. Takano, P. P. van der Werf, S. Viti, and Y. T. Yan
Astronomy &Astrophysics, volume 656, page 46 (2021)

Summary: Star formation is one of the main engines of galaxy evolution. Some galaxies harbour extreme star formation activity in their nuclear regions and are therefore target of choice to study the role and properties of the interstellar medium and its chemical evolution. This is best

done with molecular spectral lines accessible by ALMA at millimeter/submillimeter wavelengths. The main goal of the ALMA large program ALCHEMI (an ALMA Comprehensive High-resolution Extragalactic Molecular Inventory) was to unveil the molecular richness of the central region of the prototypical nearby starburst galaxy NGC 253 at an unprecedented combination of sensitivity, spatial resolution, and frequency coverage (Martin et al. 2021). The unbiased spectral survey of the ALMA bands 3 to 7, at a spatial resolution below 30 pc reveals of forest of spectral lines from the inner region of NGC 253 that provides a unique template for studies of star-forming galaxies in the early Universe (see Fig. 3.2). Several additional publications are already expanding the investigations of this golden dataset and more work is on the way. The Nordic ARC node was closely involved with the design, coordination, quality control of the observations, and in reducing data in this ALMA large program.

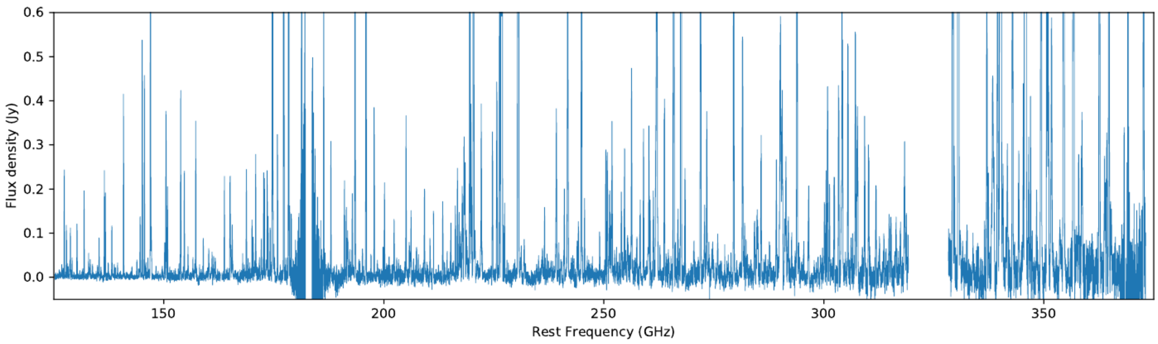

Figure 3.2. *Full spectral coverage obtained with the ALMA Compact Array (ACA 7m) alone, extracted from the position of brightest molecular emission.*

Observational identification of a sample of likely recent common-envelope events
Khouri, Theo; Vlemmings, Wouter H. T.; Tafoya, Daniel; Pérez-Sánchez, Andrés F.; Sánchez Contreras, Carmen; Gómez, José F.; Imai, Hiroshi; Sahai, Raghvendra
Nature Astronomy, volume 6, page 275 (2021)

Summary: One of the most poorly understood stellar evolutionary paths is that of binary systems undergoing common-envelope evolution, when the envelope of a giant star engulfs the orbit of a companion. The interaction that ensues leads to a great variety of astrophysical systems and associated phenomena, but happens over a very short timescale. Unfortunately, direct empirical studies of this momentous and complex phase are difficult at present because few objects experiencing, or having just experienced, common-envelope evolution are known. In this paper the authors present Atacama Large Millimeter/submillimeter Array observations of minor CO isotopologues towards a sample of sources known as water fountains, which reveal that almost all of them recently lost a substantial fraction of their initial mass over a timescale of less than a few tens to a few hundreds of years. The only known mechanism able to explain such rapid mass ejection, corresponding to a large fraction of the stellar mass, is the common-envelope evolution. A stellar population analysis shows that the number of water-fountain sources in the Milky Way is comparable to the expected number of common-envelope events that involve low-mass evolved stars. Thus, the known sample of water-fountain sources accounts for a large fraction of the systems undergoing a common-envelope phase in our Galaxy. As one of the distinguishing characteristics of water-fountain sources is their fast bipolar outflow, we conclude that outflows and jets play an important role right before, during or immediately after the common-envelope phase. See Fig. 3.3 for an illustration.

Figure 3.3. *Artist's impression of a view from a common envelope system in which two stars have just started to share the same atmosphere. The bigger star, a red giant star, has provided a huge, cool, atmosphere which only just holds together. The smaller star orbits ever faster round the stars' center of mass, spinning on its own axis and interacting in dramatic fashion with its new surroundings. The interaction creates powerful jets that throw out gas from its poles, and a slower-moving ring of material at its equator. Credit: Danielle Futselaar, artsource.nl*

3.2 APEX

[Module 3]

Linking ice and gas in the λ Orionis Barnard 35A cloud

G. Perotti, J. K. Jørgensen, H. J. Fraser, A. N. Suutarinen, L. E. Kristensen, W. R. M. Rocha, P. Bjerkeli, and K. M. Pontoppidan

Astronomy & Astrophysics, volume 650, page A168 (2021)

Summary: The determination of gas and ice abundances of CO and CH_3OH is an important part of establishing the interaction between dust, gas, and ice in star-forming regions. APEX, together with Submillimeter Array data, was used to determine the distribution of gaseous methanol around the star-forming molecular cloud B35A.

Physical Conditions in the LMC's Quiescent Molecular Ridge: Fitting Non-LTE Models to CO Emission

M. K. Finn, R. Indebetow, K. E. Johnson, A. H. Costa, C.-H. R. Chen, A. Kawamura, T. Onishi, J. Ott, K. Tokuda, T. Wong, and S. Zahorecz

Astrophysical Journal, volume 917, page 106 (2021)

Summary: The APEX telescope was used to observe CO(2-1) and ^{13}CO(2-1) in the molecular ridge of the Large Magellanic Cloud (LMC), see Fig. 3.4. The data was analysed together with ALMA compact array data and earlier CO(1-0) data. The multi-line data allow for temperature, H_2 density, and CO column density determinations of the southern part of ridge cloud. The peaks in H_2 density correlates well with the presence of young stellar objects. The APEX observations were carried out with the SHFI receiver in its last year of operation.

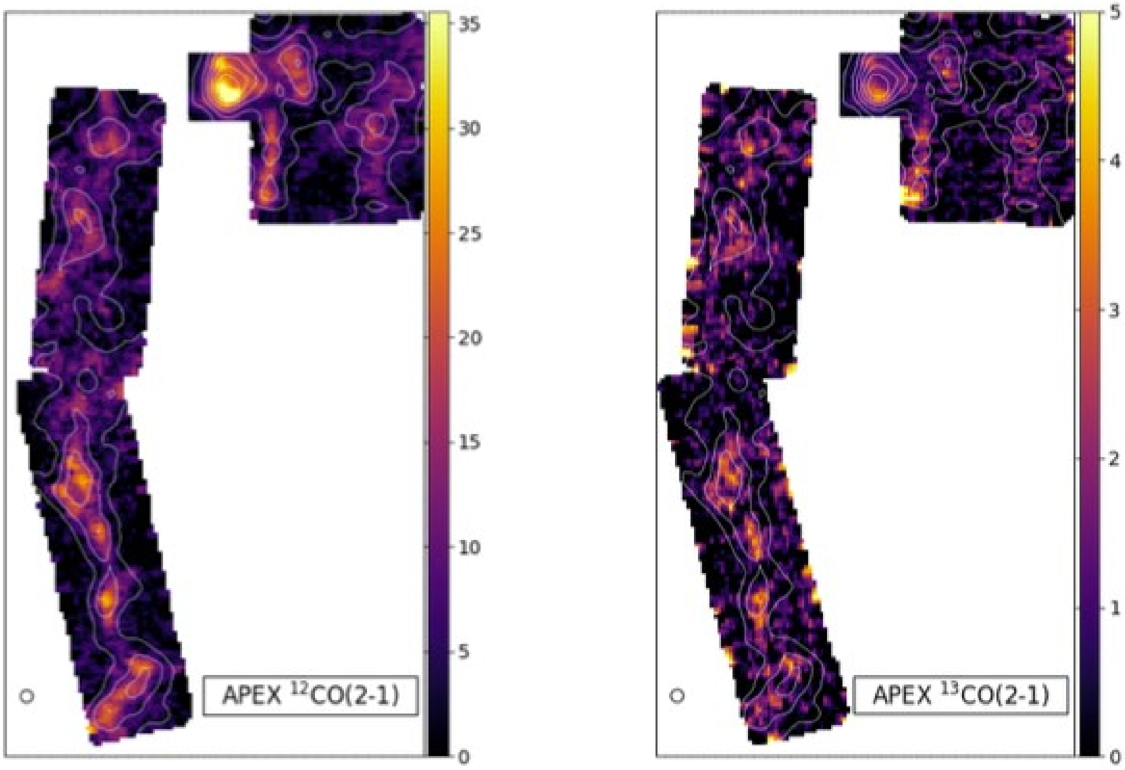

Figure 3.4. *APEX on-the-fly maps of the CO(2-1) and ^{13}CO(2-1) transitions (around 220-230 GHz) toward the southern part of in a molecular ridge located in the Milky Way's satellite galaxy LMC – only observable from the southern hemisphere. The bright spot in the upper part is the HII region N171.*

3.3 Astronomical VLBI

[Module 4]

Event Horizon Telescope observations of the jet launching and collimation in Cen A
M. Janssen, …., J. Conway, …, M. Lindqvist, ….
Nature Astronomy, volume 5, page 1017 (2021)

Summary: The Event Horizon Telescope (EHT, including APEX) Collaboration, which is known for capturing the first image of a black hole in the galaxy Messier 87, has imaged the heart of the nearby radio galaxy Centaurus A in unprecedented detail at 228 GHz, Janssen et al. 2021. Figure 3.5 shows a highly collimated, asymmetrically edge-brightened jet as well as the fainter counterjet. Janssen et al. (2021) find that the source structure of Centaurus A resembles the jet in Messier 87 on ~500 gravitational radii scales remarkably well. Furthermore, they identify the location of Centaurus A's SMBH with respect to its resolved jet core and conclude that the source's event horizon shadow should be visible at terahertz frequencies. This location further supports the universal scale invariance of black holes over a wide range of masses.

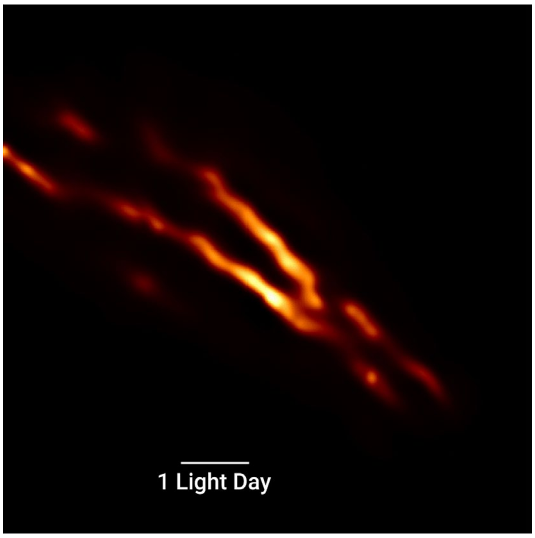

Figure 3.5. *Reconstruction of the jet image structure of Centaurus A derived from the EHT data using a regularized maximum likelihood method (Janssen et al. 2021).*

Parsec-scale faint jets in the changing-look Seyfert galaxies NGC 2617 and Mrk 590
J. Yang, I.M. van Bemmel, Z. Paragi, S. Komossa, F. Yuan, X. Yang, T. An, J.Y. Koay, C. Reynolds, J.B.R. Oonk, X. Liu, Q. Wu
Monthly Notices of the Royal Astronomical Society, volume 502, page L61 (2021a)
and
J. Yang, Z. Paragi, R.J. Beswick, W. Chen, I.M. van Bemmel, Q. Wu, T. An, X. Wu, L. Fan, J.B.R. Oonk, X. Liu, W. Wang
Monthly Notices of the Royal Astronomical Society, volume 503, page 3886 (2021b)

Summary: Broad Balmer emission lines in some active galactic nuclei (AGNs) displays dramatic changes in their amplitude, even disappearance and re-appearance happens. Such AGNs are classified as changing-look AGNs. Mrk 590 and NGC 2617 are two well-known changing-look AGNs showing multi-band continuum outbursts and remarkable changes of their Seyfert types. To track their past accretion and ejection activity, Yang et al. (2021a, 2021b) observed them with the EVN. Figure 3.6 reveals that both sources display a linear structure indicating the low-luminosity radio jet activity from the accreting supermassive black holes. The findings of the faint jets provide further strong support for variable accretion as the origin of the Seyfert type changes.

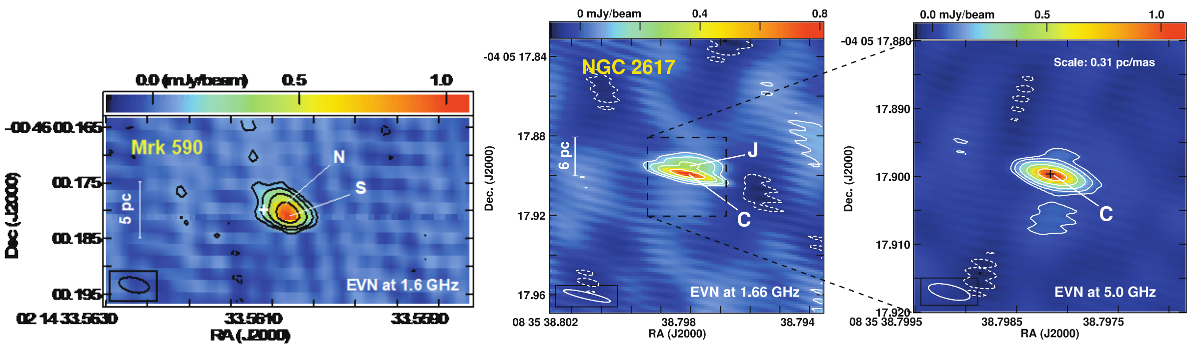

Figure 3.6. *The total intensity images of the changing-look AGNs Mrk 590 (left) and NGC 2617 (right). The crosses mark the optical Gaia positions. The contours start from 2.5 sigma and increase by a factor of -1, 1, 2, ….*

3.4 LOFAR

[Module 5]

The search for radio emission from the exoplanetary systems 55 Cancri, υ Andromedae, and τ Boötis using LOFAR beam-formed observations

Jake D. Turner, Philippe Zarka, Jean-Mathias Grießmeier, Joseph Lazio, Baptiste Cecconi, J. Emilio Enriquez, Julien N. Girard, Ray Jayawardhana, Laurent Lamy, Jonathan D. Nichols and Imke de Pater

Astronomy & Astrophysics, volume 645, page A59 (2021)

Summary: The LOFAR telescope has considerable potential for a unique detection of exoplanets. At low radio frequencies, LOFAR can detect planetary auroral emissions, that is the emissions from the interaction between a host stellar wind and planetary magnetic field. Such a detection would therefore imply the presence of magnetic fields around exoplanets, a feature often seen as a precondition for life on Earth. In this paper, the first tantalizing indications of such emissions are reported. The authors report circularly polarised (typically associated with geo-cyclotron radiation) emissions in the interval between 21-30 MHz with 3σ in three different fields. The observations presented in the paper are not a definitive detection, and more work and further observations are needed if a full detection is to be made, and since there is still room for improvement, there is great promise for this observational technique for expanding our understanding of habitable exoplanets.

LOFAR Deep Fields: probing a broader population of polarized radio galaxies in ELAIS-N1

N. Herrera Ruiz, S. P. O'Sullivan, V. Vacca, V. Jelić, B. Nikiel-Wroczyński, S. Bourke, J. Sabater, R.-J. Dettmar, G. Heald, C. Horellou, S. Piras, C. Sobey, T. W. Shimwell, C. Tasse, M. J. Hardcastle, R. Kondapally, K. T. Chyży, M. Iacobelli, P. N. Best, M. Brüggen, E. Carretti and I. Prandoni

Astronomy & Astrophysics, volume 648, page A12 (2021)

Summary: In this work, the authors have studied the population of polarized sources in the ELAIS-N1 field as part of the LoTSS Deep Field project. The LOFAR Two-metre Sky Survey (LoTSS) aims to survey the whole northern sky at 6 arcseconds resolution with a declination-dependent sensitivity which will typically be around 100 µJy/beam. This study looks at the polarised sources in the field. It estimates the density of polarised sources to be 1.6 per square degree. Such density estimates are a key step towards generating Faraday rotation measure maps, that is widefield maps of the interstellar medium. It is also an invaluable contribution to polarimetric catalogues at the lowest radio frequencies.

3.5 Onsala 20 m telescope single dish

Hunting for the elusive methylene radical

Jacob, A.M., Menten, K.M., Gong, Y., Bergman, P., Tiwari, M., Brünken, S., Olofsson, A.O.H.

Astronomy & Astrophysics, volume 647, page A42 (2021)

Summary: The Onsala 20 m telescope played a major role in observations of the methylene radical CH_2 which is important for the carbon chemistry in massive star forming regions. The 4 mm receiver was used to observe transitions near 70 GHz where the molecular oxygen opacity in the atmosphere starts to become a problem which necessitates very long integrations for each source (in particular for the low-declination sources such as Orion-KL). The study tentatively confirms the notion that CH_2 emission arises in dilute layers of PDRs (Photon Dominated Regions, e.g., a part of a molecular cloud illuminated by hot, ionising stars), see Fig. 3.7.

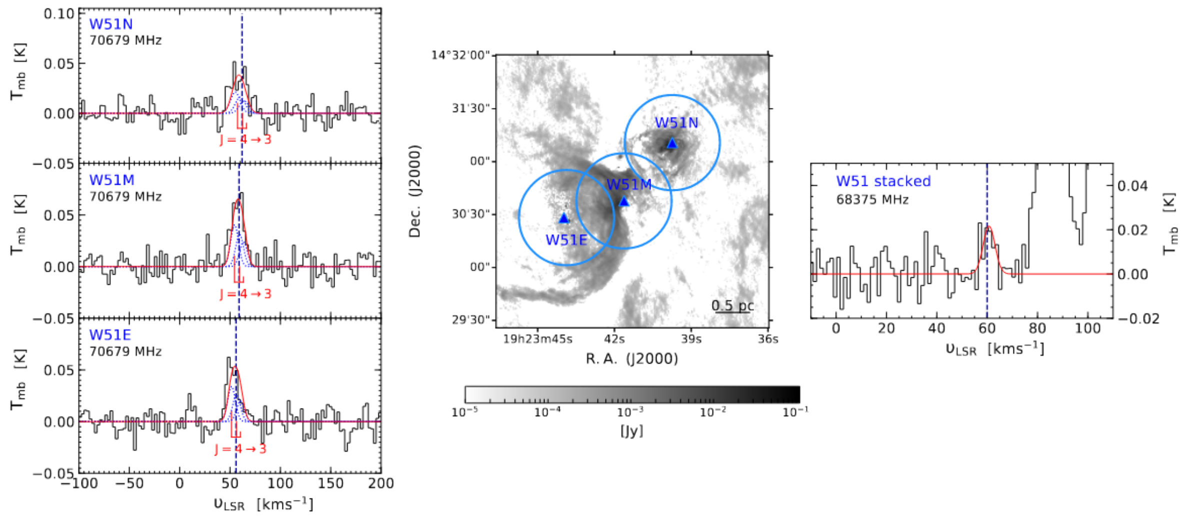

Figure 3.7. *Left & Right: Spectra of multiple hyperfine structure lines within the ortho CH_2 J=5-4,4-3 transitions towards three positions in the massive star forming region W51. The lower frequency 5-4 lines (right) were stacked and averaged over all positions. The strong lines to the right are contamination from the methyl acetylene molecule. Centre: The observed positions indicated with beam sizes, on top of a 14.5 GHz continuum map which shows the distribution of plasma in the region.*

Detection of two bright radio bursts from magnetar SGR 1935 + 2154
Kirsten, F., Snelders, M.P., Jenkins, M., Nimmo, K., van den Eijnden, J., Hessels, J.W.T., Gawroński, M.P., and Yang, J.
Nature Astronomy, volume 5, page 414 (2021)

Summary: In April 2020, two telescope in North America (CHIME/FRB and STARE2) independently detected the brightest flashes from a highly magnetised neutron star (a "magnetar") that we have ever seen in our Galaxy. Hoping to observe more flashes from this particular star, we stared at it with four European radio telescopes – the 20 m and 25 m dishes at Onsala, the 30 m dish in Westerbork, The Netherlands, and the 32 m dish in Torún, Poland – for more than four weeks straight. The different stations observed at different frequencies just to make sure we would really catch a burst. In late May 2020 we indeed caught not just one but two bursts in close succession! These two bursts were a lot fainter than those that CHIME/FRB and STARE2 had seen, proving that this magnetar generates flashes from the very faint to the very bright end. This is important knowledge because it gives us clues about a much bigger puzzle: what are fast radio bursts? These are similar flashes coming from stars that live outside our own Galaxy. See Fig. 3.8 for an illustration.

Figure 3.8. *Artist's impression of the four radio telescopes observing the Galactic magnetar SGR 1935+2154 (inset in the top left corner). The blue line indicates the flashes as observed by the Westerbork radio telescope in The Netherlands. (Credit: Daniëlle Futselaar / ASTRON, artsource.nl)*

Comet observations

Comet observations of hydrogen cyanide and methanol continued in 2021 including one case where a rather unique long-term monitoring of methanol could be started. A paper regarding earlier such observations with the 20 m telescope by Bergman et al. was accepted for publication in Astronomy & Astrophysics in early 2022 [to be presented in next year's activity report].

3.6 Geosciences

[Module 6]

Short-baseline interferometry local-tie experiments at the Onsala Space Observatory.

E. Varenius, R. Haas, T. Nilsson T

Journal of Geodesy, volume 95, page 54, (2021)

Summary: We present results from observation, correlation and analysis of interferometric measurements between the three geodetic very long baseline interferometry (VLBI) stations at the Onsala Space Observatory. In total, 25 sessions were observed in 2019 and 2020, most of them 24 h long, all using X band only. These involved the legacy VLBI station ONSALA60 and the Onsala twin telescopes, ONSA13NE and ONSA13SW, two broadband stations for the next-generation geodetic VLBI global observing system (VGOS). We used two analysis packages: *vvSolve* to pre-process the data and solve ambiguities, and *ASCOT* to solve for station positions, including modelling gravitational deformation of the radio telescopes and other significant effects. We obtained weighted root mean square post-fit residuals for each session on the order of 10–15 ps using group-delays and 2–5 ps using phase-delays. The best performance was achieved on the (rather short) baseline between the VGOS stations. As the main result of this work, we determined the coordinates of the Onsala twin telescopes in VTRF2020b with sub-millimetre precision. This new set of coordinates should be used from now on for scheduling, correlation, as a priori for data analyses, and for comparison with classical local-tie techniques. Finally, we find that positions estimated from phase-delays are offset ∼ *+3* mm in the up-component with respect to group-delays. Additional modelling of (elevation dependent) effects may contribute to the future understanding of this offset.

High-temporal-resolution wet delay gradients estimated from multi-GNSS and microwave radiometer observations.
T. Ning, G. Elgered
Atmospheric Measurement Techniques, volume 14, page 5593 (2021)

Summary: We have used 1 year of multi-GNSS observations at the Onsala Space Observatory on the Swedish west coast to estimate the linear horizontal gradients in the wet propagation delay. The estimated gradients are compared to the corresponding ones from a microwave radiometer. We have investigated different temporal resolutions from 5 min to 1 d. Relative to the GPS-only solution and using an elevation cutoff angle of 10∘ and a temporal resolution of 5 min, the improvement obtained for the solution using GPS, Glonass, and Galileo data is an increase in the correlation coefficient of 11 % for the east gradient and 20 % for the north gradient. Out of all the different GNSS solutions, the highest correlation is obtained for the east gradients and a resolution of 2 h, while the best agreement for the north gradients is obtained for 6 h. The choice of temporal resolution is a compromise between getting a high correlation and the possibility of detecting rapid changes in the gradient. Due to the differences in geometry of the observations, gradients which happen suddenly are either not captured at all or captured but with much less amplitude by the GNSS data. When a weak constraint is applied in the estimation of process, the GNSS data have an improved ability to track large gradients, however, at the cost of increased formal errors.

Water vapour radiometry in geodetic very long baseline interferometry telescopes: assessed through simulations.
P. Forkman, J. Flygare, G. Elgered
Journal of Geodesy, volume 95, page117, (2021)

Summary: The accuracy of geodetic Very Long Baseline Interferometry (VLBI) is affected by water vapour in the atmosphere in terms of variations in the signal propagation delay at the different stations. This “wet” delay may be estimated directly from the VLBI data, as well as from independent instruments, such as collocated microwave radiometers. Rather than having stand-alone microwave radiometers we have, through simulations, evaluated the possibility to use radiometric data from the VLBI receiver in the VGOS telescopes at the Onsala Space Observatory. The advantage is that the emission from water vapour, as sensed by the radiometer, originates from the same atmospheric volume that delays the VLBI signal from the extra-galactic object. We use simulations of the sky brightness temperature and the wet delay together with an assumption of a root-mean-square (rms) noise of the receiver of 1 K, and observations evenly spread between elevation angles of 10∘∘–90∘∘. This results in an rms error of the estimated equivalent zenith wet delay of the order of 3 mm for a one frequency algorithm, used under cloud free conditions, and 4 mm for a two frequency algorithm, used during conditions with liquid water clouds. The results exclude rainy conditions when the method does not work. These errors are reduced by a factor of 3 if the receiver error is 0.1 K meaning that the receivers’ measurements of the sky brightness temperature is the main error source. We study the impact of ground-noise pickup by using a model of an existing wideband feed. Taking the algorithm uncertainty and the ground noise pickup into account we conclude that the method presented will be useful as an independent estimate of the wet delay to assess the quality of the wet delays and linear horizontal gradients estimated from the VLBI data themselves.

3.7 Device physics and Terahertz technology

[Module 8]

Millimeter-Wave Wideband Waveguide Power Divider With Improved Isolation Between Output Ports

A Gouda, C. D. López, V. Desmaris, D. Meledin, A. B. Pavolotsky, V. Belitsky.

IEEE transactions on Terahertz Science and Technology, volume 11, page 408 (2021)

Summary: We report on an improved compact wideband waveguide T-junction power divider, especially suited for millimeter-wave and THz frequencies. In modern radio astronomy receivers operating at THz frequencies and employing a side band separation scheme, it could advantageously be implemented to practically equally split the LO signal in two signals delivered in-phase between the two mixers chips, for even better side band rejection ratio and noise performances of the receiver.

In fact, the device (Fig. 3.9) incorporates substrate-based elements into a waveguide structure to provide the output port's isolation and matching. The internal port is introduced at the apex of the T-junction formed as an E-probe on a substrate. This facilitates efficient coupling of the reflected energy from the output port to a novel thin-film-based resistive termination integrated with the E-probe onto the same substrate and fabricated by means of thin-film technology.

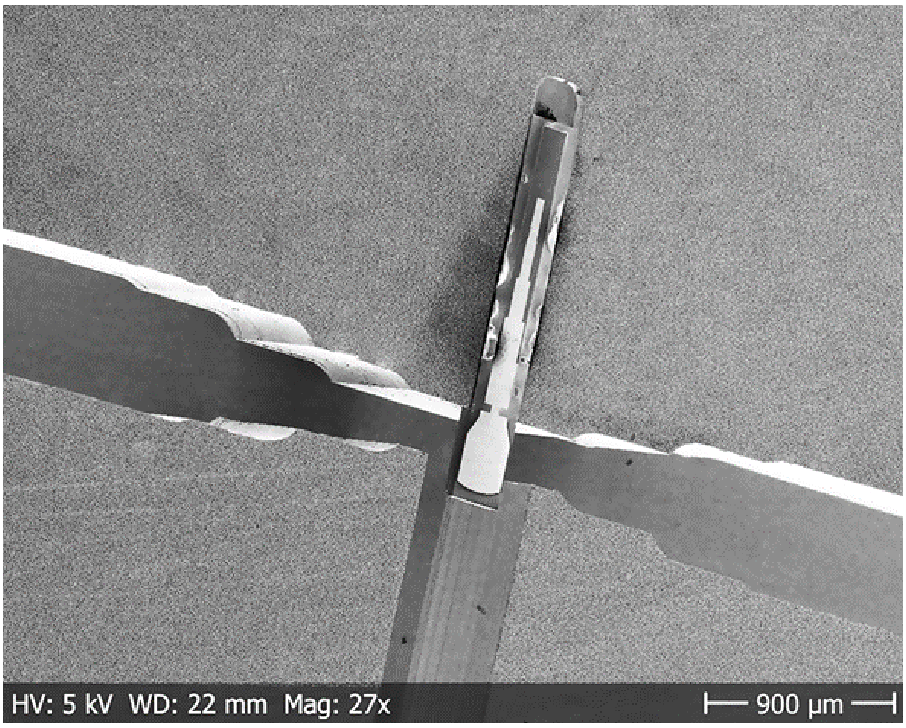

***Figure 3.9.** SEM picture of the mounted chip in the substrate at the apex of the input waveguide, between the two output waveguides.*

A demonstrator power divider was designed, simulated, and fabricated for the frequency band 150-220 GHz to experimentally verify the theoretical and simulated performance. The results showed excellent agreement between the simulations and measurements with the device demonstrating a remarkable return loss of 20 dB for both the input and output ports for a three-port device with equal split and isolation better than 17 dB between the output ports. Furthermore, the measured insertion loss is less than 0.3 dB and the amplitude and phase imbalance are 0.15 dB and 0°, respectively (Fig. 3.10). Moreover, the divider's remarkable tolerance to the dimensions and sheet resistance of the resistive material of the built-in absorbing load makes the device a very practical component for millimeter-wave and THz systems, in particular radio-astronomy receivers.

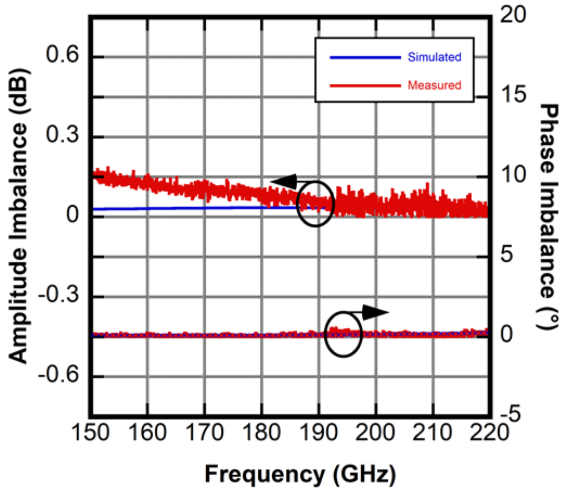

Figure 3.10. *Measured and simulated amplitude and phase imbalance of the improved coupler.*

4 Instrument upgrades and technical R&D

4.1 ALMA

[Modules 2 & 8]

With respect to R&D on ALMA receivers, in November 2020 GARD has kicked off and continued in 2021 a new three-year ESO funded project as part of ALMA Update Program dedicated to ALMA Band 6 and 7 cold cartridge demonstrator. This project targets for the design, construction and experimental verification of a demonstrator receiver cartridge with a goal to cover the combined ALMA bands 6 and 7 frequency range (i.e. 211-375 GHz) aiming to explore instantaneous IF bandwidth up to 16 GHz (e.g. frequency range 4–20 GHz). It strongly relies on the results SIS process development carried out in the yet another ESO funded study related to the development of a new type of superconducting tunnel junctions, SIS, with AlN tunnel barrier and having a junction area down to a square micron area. The later part is being carried out using GARD dedicated equipment in the Chalmers Clean Room Facility, MC2.

In this period, the Nordic ARC has also continued providing support for the ALMA Development Study "High-Cadence Imaging of the Sun" (PI: S. Wedemeyer). A dedicated contribution in the form of sustained support to this project by our node staff was agreed upon for the second half of 2021 until the end of the study in 2022.

4.2 APEX

[Modules 3 and 8]

In early 2020, just before the outbreak of the pandemic, three new receivers were installed at APEX. One of these was a 345 GHz receiver, filling the last empty slot in the SEPIA cryostat. This receiver was developed at GARD/OSO. The other two receivers were the nFLASH 230 GHz and 460 GHz instruments developed by the Max Planck Institute (MPI) for Radio

Astronomy. Because of the pandemic the technical and sky commissioning of these receivers lasted into 2021. In May 2021 the three receivers were accepted as APEX facility instruments by the APEX board. The new SEPIA 345 GHz receiver was used during 2021 for around 155 hours of scientific observations.

The GARD/OSO team led the test and commissioning work of the 345 GHz on a remote basis and the last commissioning tasks were completed in early 2021 and an extensive commissioning report was completed in March 2021. During 2021 further refurbishments and improvements of the other SEPIA receivers were made. Due to travel restrictions, the local APEX staff carried out the actual installations with remote support from GARD/OSO. A new frequency synthesizer was sent to APEX to provide a more stable reference signal to all SEPIA receivers. In July, the SEPIA cryostat cold head showed signs of aging and was replaced in September 2021. A harmonic mixer for the 180 GHz channel was replaced in May and a faulty power amplifier for one of the SEPIA 660 GHz polarization channels was replaced in September. The SEPIA control software was updated to allow for the new hardware.

4.3 Astronomical VLBI

[Module 4]

OSO is involved in the VLBI related H2020 project JUMPING JIVE. During the reporting period, OSO has continued its involvement in work package 8, (WP8, Global VLBI interfaces). WP8 addresses two main issues, the first is scheduling of observations and the second is the continuous monitoring of the status of stations participating in VLBI sessions.

Since May 2019, the Onsala 25 m telescope has taken part in a VLBI-campaign (PRECISE) that regularly observes Fast Radio Bursts that have been reported to repeat as discovered by the CHIME telescope in Canada. The ad-hoc array is composed of most of the smaller (<40 m) telescopes that also take part in EVN-observations viz Onsala, Torun, Irbene, Medicina, Noto, Badary, Svetloe, Zelenchukskaya, Urumqi, Shanghai, and Westerbork. Since January 2020, the telescopes in Effelsberg and Sardinia also take part in a subset of the observations. The 25 m telescope was used for this project on 49 days in 2021. In addition to that, OSO has been monitoring repeating CHIME FRBs, magnetars and HMXBs as potential galactic sources of FRBs. This work is done in collaboration with Westerbork in the Netherlands and Torún in Poland. In total, the 25 m telescope was used for this project on 110 days in 2021. For data recording and data processing purposes, the dedicated server ('flexbuff') was upgraded, doubling the available disk space to ~220 TB for data recording. In 2021, three master student projects were conducted at OSO, all three were related to FRB-science. One project was aimed at understanding the response of the signal chain to extremely bright bursts from FRBs and/or magnetars. To this end, a vector signal generator was borrowed from Rhode & Schwarz in Gothenburg, and software to generate and inject bright FRB-like signals was developed. Two further master thesis projects were devoted to the development of an FRB-backend that is based on FPGA technology. The students developed and tested software and firmware to implement a detection pipeline that will, eventually, reduce the resources required to perform FRB observations.

4.4 LOFAR

[Module 5]

Last year saw a considerable development of the software for local control of LOFAR stations within the EU funded project LOFAR for Space Weather (LOFAR4SW). LOFAR can be configured in different modes, the most common being the International LOFAR Telescope or ILT mode. But it is also possible for each LOFAR station, such as the one owned and operated by OSO, to be controlled locally. It is then in so-called LOCAL mode.

During the year, the development of LOFAR instrument upgrades to LOFAR2.0 have reached a critical point. E.g., the DUPLLO phase of the LOFAR2.0 project has been funded. Part of upgrade designs were investigated within the LOFAR4SW. These upgrades will amongst many other things will allow observations with both the LBA and HBA arrays simultaneously. LBA and HBA are currently used separately due to data-rate limitation in processing.

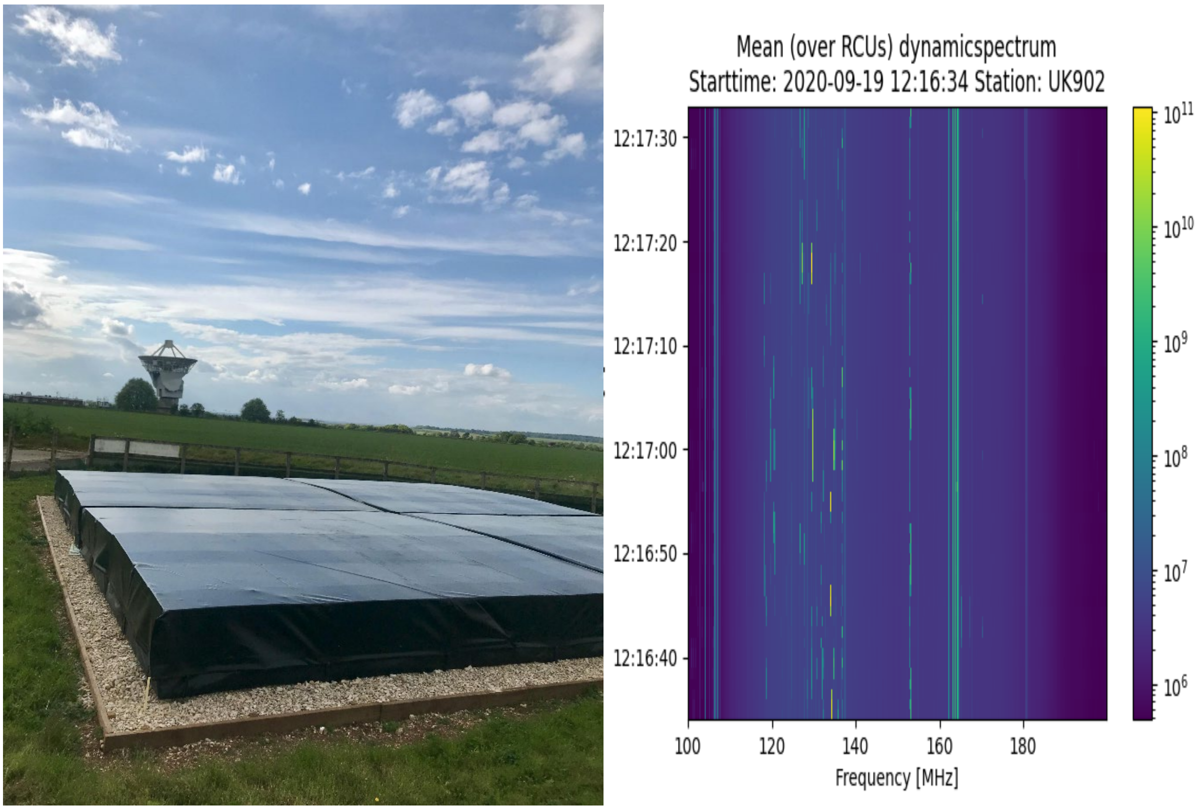

Figure 4.1. *The LOFAR4SW prototype station in Chilbolton UK (left), and "first light" data from this station (right).*

The route towards LOFAR2.0 technically, and LOFAR4SW operationally and software-wise, took a huge step forward last year when a prototype station in Chilbolton UK (see Fig. 4.1) was commissioned. Engineers from Onsala Space Observatory were part of the leading effort to showcase the LOFAR4SW technology, such as event driven scheduling and operations, continuous quasi real-time data reduction, and advanced high-level pipeline such as solar wind tracking, coronal mass ejection (CME) magnetic field determination and solar burst type categorization. The CMR pipeline uses pulsar polarisation monitoring, while solar bursts are categorized using machine learning techniques. The software holding all these together was developed at OSO.

4.5 The Onsala 20 m telescope

[Modules 4,6]

No major technical upgrade was implemented on the telescope in 2021. More features were added to the Bifrost control system which further improves the capability to carry out autonomous observations (such as general variable management). Preparatory work was done to replace ethernet communication & control units that cause communication hangups and generate some RFI meaning that they have to be turned off for certain experiments. Preparations were also begun to replace the hardware on which the Linux live system is run that actually controls the servomotor amplifiers for the telescope tracking. This is a major undertaking since the switch will be to a new architecture and the control code is highly specialised and sensitive. Safety procedures and techniques were improved that will help during the annual antenna service rounds.

4.6 Geoscience

[Module 6]

In 2021 the VLBI Field System was further developed to become VGOS compatible. This was made possible by intensive testing and development using the Onsala twin telescopes. The new version FS10 allows real-time monitoring of system temperature and other important parameters.

A focal finder for the OTT was developed to allow optimized receiver-focus adjustment.

Additionally, a shutter system for the OTT feed horn was designed and tested. This is a protective device to suppress radio frequency interference (RFI) disturbances when the telescopes are parked.

Concerning VGOS development, we tested various different frequency setups up to 15 GHz and successfully found fringes. Also, fringes at high data rates of up to 32 Gbit/s were achieved.

4.7 Development of new millimetre/sub-millimetre devices

[Module 8]

R&D activities at GARD were largely affected by the Covid-19 pandemic. GARD work include effort with equipment, e.g., in the laboratories and Chalmers Clean Room facility. Because of Covid-19, the staff presence and work were limited following the recommendations by Swedish authorities and Chalmers administration. GARD continued its R&D work anyways but we had to change the way we work to appropriate constrains and circumstances.

During 2021, GARD worked on several internal and external projects. A significant effort was made to improve technology of installing chips and mounting circuits in the cryogenic blocks operating at 4 K physical temperature. Also, serious efforts were made to improve further the wire-bonding technology used for cryogenic mixers and amplifiers. Special focus was also put in the possible improvement of our milling machine: a full service was performed and an upgraded tool measuring system was installed for improved processing accuracy and better control of linear dimensions of the produced hardware.

Furthermore, GARD designed, built and commissioned a laboratory cryostat for 4 K operation, aiming at replacing the use of cryostats with extremely expensive liquid helium for testing of the micro fabricated components. For this purpose, a specific software for controlling the measurement equipment and data acquisition was developed for most efficient device characterization at 4 K. In addition, another 4 K cryostat was designed and started being assembled to text mixers and receiver systems.

GARD also successfully completed the project on ALMA Upgrade Program on "SIS Junction Technology Development for Wideband 2SB Receivers" earlier in 2020. As a result, ESO has supported two new projects, both kicked-off in November 2020. One study is dedicated to the SIS process development to serve next generation receivers for ALMA. Another project targets for ALMA Band 6 and 7 cold cartridge demonstrator. In 2021, both projects progressed significantly towards their project goals. The two studies are strongly interrelated as the second one relies on the outcome of the SIS process development being performed in the first one, and simultaneously, gives immediate feedback to it.

Within the frame of the ALMA Band 2 Development and pre-production project, where GARD owns the role of the cold cartridge designer in this prestigious international project with partner institutions from the Netherlands (NOVA, Groningen), and Italy (INAF, Palermo, GARD completed in 2021 the design of design of two cartridge receivers and produced most of the unique and dedicated hardware in its own workshop for the final assembly at NOVA and further receiver tests at INAF, prior a Critical Design Review in the spring of 2022.

As an example of the THz components, we present here the results presented in the licentiate thesis of C. D. Lopez, defended May 2021. Figure 4.2 demonstrates the idea behind the micro-fabricated ultra wideband waveguide to substrate transitions and its performances.

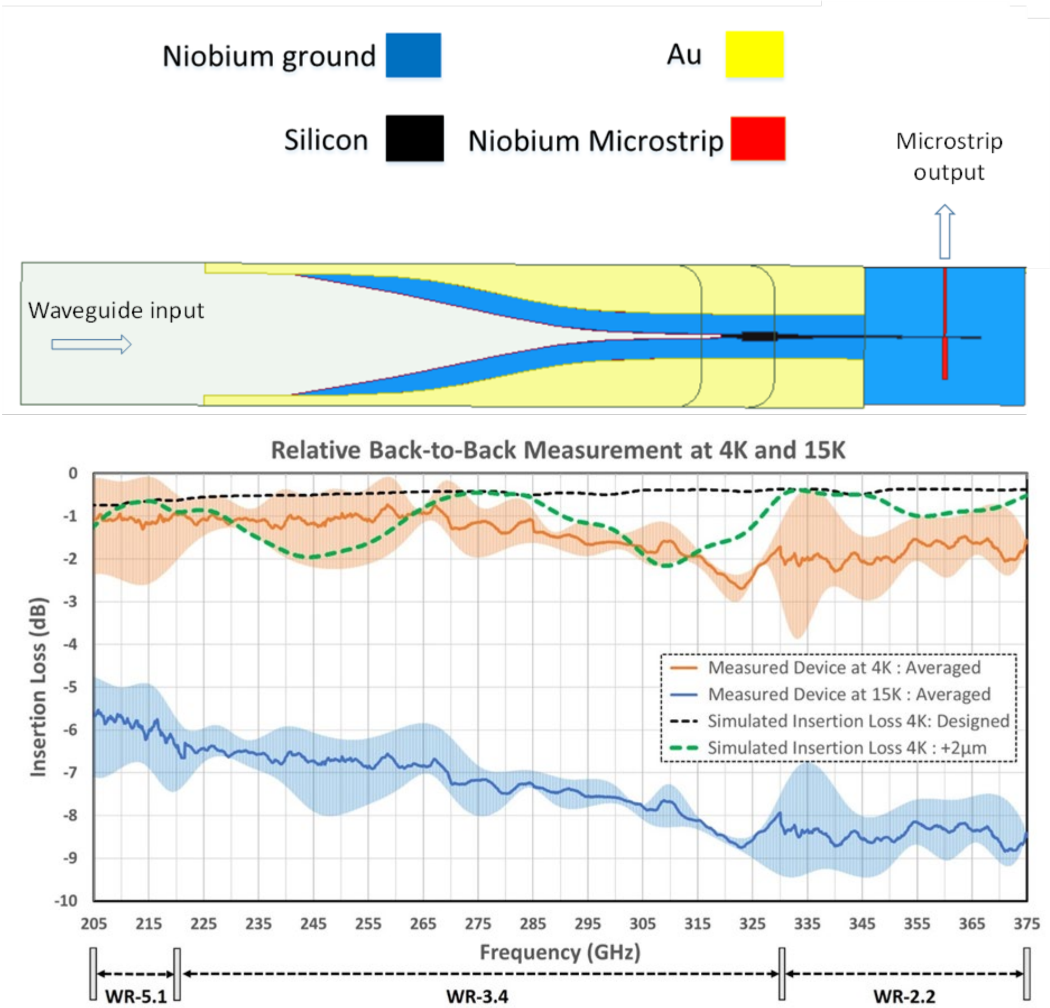

Figure 4.2. *Top: Conceptual picture of the waveguide to microstrip transistion using fins, slotlines and a balun. Bottom: Relative insertion loss at 4 K and 15 K for two fabricated back-to-back transistions.*

5 SKA – The Square Kilometre Array

[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 SKA1 operating at cm wavelengths (SKA1-mid) will be constructed in South Africa by adding 133 dishes to the existing 64 dish MeerKAT array (inaugurated in July 2018). The metre wavelength part (SKA1-low) will be built in Australia utilizing the infrastructure of the MWA SKA precursor telescope. The global headquarters of the SKA project are located at Jodrell Band in the UK.

A major milestone in the SKA project was reached in January 2021 with the establishment of the SKA Observatory Intergovernmental Organization (SKAObs) with the SKAObs council shortly after approving the start of construction of the SKA. Already during 2021 a number of high value construction contracts have been signed. The pace of construction has however been slowed relative to plans due to the persistent COVID pandemic and severe restrictions of travel to both Australia and South Africa that applied throughout 2021. Despite these delays it is still expected that Phase 1 of the SKA project (SKA1) will be completed on schedule by 2028.

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 SKA1 construction and operations phase is identified and is committed. In October 2021 Chalmers signed an agreement with SKAObs for Chalmers to represent Sweden within the SKA project for two years while work continues toward Sweden as a nation formally signing the SKAObs international convention. The signed agreement between SKAObs and Chalmers allows Swedish companies to be fully engaged in the industrial procurement process that has started for supplying components of the SKA1 system. During November 2021 a contract covering Swedish construction funding between VR and Chalmers came into force, with this funding being used in December 2021 to pay the Swedish 2021 financial contribution to SKAObs.

5.2 Swedish industrial contributions to SKA1 constructions

Sweden is the 'Level 1' lead for two work packages within SKA construction, namely for the SKA1-mid Band 1 receiver and for SKA1-mid Digitizers. In addition, a Swedish company (Low Noise Factory) ïs working as a Level 2 supplier of Low Noise Amplifiers to at least one other SKA1-mid receiver band in addition to Band 1. For the digitizer work that Sweden leads at Level 1 the Gothenburg company Quamcon continued under contract to work on the industrialization of the SKA1-mid Band 1,2,3 Digitizer design.

5.3 SKA Observatory Development Programme

The proposed SKA Observatory construction plan provides, once constructions has begun in earnest (2022 onward), for an Observatory Development Programme (ODP) developing future SKA technology. Via the ODP SKA Observatory central funding will be available to fund studies and prototyping. The ODP will initially be at a moderate level but will grow in scope toward the end of the SKA1 construction phase (mid-to-late 2020's). OSO continues to discuss and prepare with international partners for future SKA development work within the frame of the coming ODP; in particular within the areas of next generation Digitizers and Wideband Single Pixel feeds.

5.4 SKA Regional Centre planning and SKA Data Challenges

A vital component of the SKA project will be a network of SKA Regional Centres (SRCs) which will collectively form the archive of the data that SKA users will access. At computer centres close to the SKA1-mid and SKA1-low telescopes in South Africa and Australia raw SKA data will first be converted into Observatory Data Products (such as data cubes of radio intensity versus spatial coordinates and frequency) – which will then be transferred to the distributed SRC sites. At SRC sites these ODPs will be converted into Advanced Data Products (ADPs) such as catalogues of sources (requiring AI and Machine Learning processing). Sweden is expected to provide its share of SRC resources in terms of data storage and computation. During 2021 Sweden fully participated in the SRC Steering Committee (SRCSC) whose mission is to plan in detail the worldwide SRC network.

During the year the SRCSC's six working groups (WG) developed specifications for the operational SRC network. The participating Swedish SRCSC-WG representatives in this effort were a mixture of staff drawn from OSO (4 people), members of the new Chalmers e-Commons organisation (3 people) and from SNIC (1 person). Among other activities the Swedish participants in the SRC WGäs helped organize the first training for the user community in handling the large expected SKA data sets. A vital aspect of future SRC future functionality will be applying Machine Learning (ML) and Artificial Intelligence (AI) techniques to the analysis of SKA data. To help develop this aspect during 2021 a Swedish team participated in SKA Data Challenge 2 (SDC2) under the team name FORSKA-Sweden. The team consisted of OSO staff plus ML experts from the Fraunhofer Chalmers Centre for industrial mathematics. The challenge involved automatically identifying, using ML methods, sources in simulated HI spectral line data cubes. The FORSKA-Sweden team achieved an excellent very close 2nd place finishin the challenge.

6 Computers and networks

[Module 10]

During 2021 the internal 10 Gbps VLBI data network was upgraded to 100 Gbps, which combined with existing 100 Gbps network shared by the twin telescopes expands the possibilities for parallel high-speed recordings. With this new link it will now be possible to record 3x64 Gbps streams if needed. A further 120 TB storage was provisioned for the NAFCI (NAtional Computer InfraStructure) cluster at OSO, combined with a new RAID card to increase transfer speeds to and from the storage A further 540 TB storage was also purchased for the EVN community, (European VLBI Network), with this storage being located at the correlator JIVE (Joint Institute for VLBI ERIC).

The OSO cluster at the SNIC–C3SE, (SNIC: Swedish National Infrastructure for Computing; C3SE: Chalmers Centre for Computational Science and Engineering) node at Chalmers consists of a five-node cluster with 32 cores each and a dedicated NFS storage server with a capacity of 583 TB, enabling the processing of ever larger data sets from ALMA and LOFAR, (earlier dimensioned to allow an international LOFAR data set, 40 TB, plus two large ALMA data sets, 20 TB, to be processed). The OSO cluster at Onsala NAFCI, (NAtional Computer InfraStructure) consists of 106 cores cluster with a storage capacity of 460TB. A separate system at Onsala consisting of 20 cores and 280 TB including a Tesla T4 GPU, are dedicated to searching for Fast Radio Bursts (FRB).

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. Presently OSO rents multiple 10 Gbit/s fibre connections to SUNET, used for ordinary network traffic, plus a dedicated lightpath 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

[Module 10]

On behalf of European radio astronomers, the Committee on Radio Astronomy Frequencies (CRAF, https://www.craf.eu) of the European Science Foundation 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. Between June 2019-September 2021 the chairperson was from OSO (Michael Lindqvist). In addition, OSO is also contributing 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 Correspondance Group (CEPT) related issues.

Preparations for the World Radio Conference 2023 (WRC23) have continued at both the ITU-R and CEPT levels in 2021. The agenda items of most importance are the use of the high-altitude platform stations as International Mobile Telecommunications Service (IMT) base stations (HIBS), non-safety aeronautical mobile applications and space research services (SRS) applications. Other agenda items regarding the global maritime services (GMDSS) and space weather sensors are also of interest and are currently being tracked. The decision to upgrade the radio astronomy service (RAS) secondary band 608–614 MHz to a primary allocation is under consideration depending on the demand for this band in Europe. CRAF is participating in meetings, submitting documents, at all levels (including national) in order to get the support from the national telecom adminstrations.

In 2021, with the intent to coordinate efforts of the astronomical community towards the protection of the Dark and Quiet Skies, National Science Foundation's (NSF's) National Optical-Infrared Astronomy Research Laboratory (NOIRLab, https://noirlab.edu) and the Square Kilometre Array Observatory (SKAO, https://www.skatelescope.org) co-authored a proposal for an “IAU centre for the protection of the dark and quiet skies from satellite constellation interference”. The Centre will be international, interdisciplinary, and work across multiple jurisdictions to mitigate the impact of satellite constellations on astronomy at optical through radio wavelengths (Fig. 7.1). CRAF supported the proposal and is one of the bodies that will collaborate very closely with the Centre and is committed to the performance of necessary spectrum compatibility calculations and the coordination of observation programmes at European radio observatories in collaboration with the Centre. Through its member institutes, CRAF has access to all major European radio astronomical facilities and will therefore provide observations of satellite-borne emissions, which will help to analyse the overall interference situation. This is fundamental in seeking improved solutions with respect to radio astronomy. The proposal was selected by IAU early 2022.

Figure 7.1. *Starlink Satellites pass overhead near Carson National Forest, New Mexico, USA, photographed soon after launch. Credit: M. Lewinsky/Creative Commons Attribution 2.0*

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). One example of an issue during 2021 has been discussing terms of coordination with OSO and the plan for an offshore wind farm park in the Swedish economic zone off the coast of Falkenberg and Varberg.

8 Memberships of International Committees

During 2021 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 was until July chairman 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 APEX project board* – representing the three partners that operate the 12 m diameter sub-mm telescope APEX in northern Chile (the Director is a board member)
- *The International LOFAR Telescope (ILT)* Board, which oversees the operation of the ILT (the Director is a board member)

- *Jumping JIVE*, an EU-financed Horizon 2020 project to develop European VLBI (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)
- *The SKA Organisation (SKAO),* the British company that is responsible for the SKA project in its pre-construction phase (the Director and Lars Börjesson, Chalmers, are board members). Note that although most functions of the SKA project are now taken over by the new SKA Observatory Intergovernmental Organization the SKAO still formally exists to it is wound up in mid-2022.
- *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)
- *LOFAR for Space Weather (LOFAR4SW)*, an EC funded (H2020 INFRADEV) design project (the Director represents Chalmers in the project)
- *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)
- *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)
- *Galileo Scientific Advisory Committee (GSAC) of the European Space Agency* (Gunnar Elgered is a member)
- *ESF Committee on Radio Astronomy Frequencies (CRAF)* for the protection of the radio band for radio astronomical use (Michael Lindqvist was chairperson, June 2019-September 2021)
- 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 since July 2021)

9 EU projects

[Modules 2, 4, 5, 8, 9]

During the year OSO participated in three EU Horizon 2020 projects (proposals submitted in respectively 2016, 2017 and 2020): JUMPING JIVE, LOFAR4SW and ORP.

9.1 JUMPING JIVE

Joining up Users for Maximising the Profile, the Innovation and the Necessary Globalisation of JIVE (JUMPING JIVE) aims to prepare and position European VLBI for the SKA era, and to plan the role of the ERIC JIVE, as well as the EVN, in the future European and global landscape of research infrastructures. On a European scale, the proposed activities are designed to raise the profile of JIVE/EVN among scientists and operators of radio astronomical facilities, by widely advocating its science capabilities and its role as research infrastructure provider within the international radio astronomy community. These activities focus on outreach and on reinforcing science cases for the next decade. (See also Sect. 4.3.) JUMPING JIVE started December 2016 and will run for four years. In 2020, the project was extended to 31 July 2021, in order to minimise the impact of Covid-19 into the project activities.

9.2 LOFAR4SW

The LOFAR for Space Weather (LOFAR4SW) project will deliver the full conceptual and technical design for creating a new leading-edge European research facility for space weather science. It also supports outreach and dialogue with a range of stakeholders in the space weather community, regarding the possible subsequent implementation, potential future use, and governance aspects of a LOFAR4SW data monitoring facility.

Designing for LOFAR a significant upgrade in hardware, algorithms, and software will allow to create, at a fraction of the cost of building a new facility, a large-scale cutting-edge research facility providing simultaneous independent access to both the radio astronomy and the space weather research communities. LOFAR4SW will in particular address capabilities to monitor Solar dynamic spectra, scintillation measurements of densities and velocities in the inner heliosphere, and high-resolution measurements of Total Electron Content (TEC) variations in the Earth's ionosphere. A strong point of the LOFAR4SW is to uniquely enable provision of the missing link of global measurements of the interplanetary magnetic field – a key parameter in forecasting the severity of geomagnetic storms. (See also Sect. 4.4.) LOFAR4SW started December 2017 and will run for 3.5 years. In 2020, the project was extended to 28 February 2022, in order to minimise the impact of Covid-19 into the project activities.

9.3 ORP

The OPTICON RadioNet Pilot (ORP) project brings together the well-established ground-based astronomy community, in an effort 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 APEX and the EVN.

10 Conferences, workshops, schools, etc.

The Nordic ARC node provided support and computing resources for one school and hosted several online training events in 2021 (see also Sect. 1.2):

- The node provided support and computing resources for tutors and participants in the sub-mm stellar evolution hands-on sessions lead by Chalmers tutors in the Virtual OPTICON Archival School using ESO and ALMA data.
- To expand the knowledge in interferometry and ALMA of our users, the Nordic ARC node coordinated the series of online training events I-TRAIN with the European ARC Network, a regular series of Interactive Training in Reduction and Analysis of INterferometric data. In 2021, a total of 9 online trainings were hosted featuring European ARC Network experts and software tools. Besides coordination, the Nordic ARC hosted 8 of the events and were tutors in 4 of them. The live sessions were well attended, with an average number of ~30-40 participants. The series has also an

important legacy value, as all trainings are uploaded in the YouTube channel of the European ARC Network.

- Sebastien Muller was member of the SOC for the SKA Science Conference 2021.

The space geodesy and geodynamics research group arranged in March 2021 the 25th European VLBI for Geodesy and Astrometry (EVGA) Working Meeting with 170 registered participants. The EVGA 2021 meeting was held as a virtual conference.

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 in astronomy and physics courses, the 25 m telescope 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 made a virtual visit (due to the pandemic) to the Observatory as part of the course Experimental physics.

Figure 11.1. *One of the SALSA antennas in Onsala used for education and outreach. Credit: Magnus Thomasson*

12 Outreach

With the exception of the project *SALSA för högstadiet* (see below), outreach activities at OSO are funded by Chalmers and are not part of the national infrastructure's VR funding.

Construction began on the observatory's new visitor centre during summer 2021. OSO secured a 1 MSEK grant from the Hasselblad Foundation to cover initial costs for a new exhibition. A four-person team worked on developing content for the exhibition, in collaboration with colleagues from Chalmers' division for interaction design. To help define the right content, we ran four co-creation workshops involving both school pupils and adults.

A project working group involving OSO staff worked on coordinating the project in collaboration with Chalmers's fundraising office, Chalmersfastigheter and our host department at Chalmers (Space, Earth and Environment, SEE).

Visits from schools and the public during 2021 were kept to a minimum because of the pandemic, and only two physical guided tours took place. Instead of these visits we worked on digital alternatives. We developed a virtual tour (half-hour video) which has been shown in conjunction with question-and-answer sessions with school classes and other groups. The project Rymdskolan, developed by astronomers Chiara Ceccobello and Kiana Kade at our host department, provided digital interactive lessons in astronomy aimed at high-school students in Gothenburg schools in areas with low socioeconomic status.

We initiated a long-term collaboration with Lövgärdesskolan in Göteborg, together with and several other actors, aimed at increasing science capital among students, as part of the city-wide initiative *Skolan som arena*. This culminated in a "space day" held at the school in September, involving up to 100 pupils and adults.

In our VR-funded MINT project *SALSA för högstadiet* we developed and tested a new user interface for our small SALSA radio telescopes, and explored possible lesson plans to suit schoolchildren in years 7–9.

Meanwhile, the SALSA telescopes continued to be an important online resource for students, schools and amateur astronomers during the pandemic. To cater for the extra demand, a third SALSA antenna started operation in December. During 2021 the SALSA telescopes were booked for an average of 34 hours per week, with bookings of on average 2 h from a record 24 countries, among them Sweden, India, USA, Honduras and Ukraine. Users typically study the movements of interstellar gas in the Milky Way, but can also observe satellites. We provided supervision for a small number of Swedish high school projects.

Staff handled media enquiries on astronomical topics and were regularly quoted in news media. Among the year's public talks, Nordic ARC staff Tobia Carozzi and Carmen Toribio participated in Gothenburg Science Festival in a panel discussion about the future SKA telescopes; Daniel Tafoya participated in several online outreach events mainly directed to the public in Mexico.

Nordic ARC staff contributed content to the European ALMA Regional Center Network's series of three-minute videos ALMA Explained. Our contributions presented ALMA and basic interferometric principles, for example Fourier transforms and polarisation measurements, to non-experts (see also Sect. 1.2).

We communicated news from Onsala facilities and research by Chalmers scientists to the media in collaboration with Chalmers press office and partner organisations. We reported for example on the release of high-resolution data from LOFAR, the signing of an agreement between Chalmers and the SKAO, mapping water in space carried out by the Herschel Space Observatory, and new results from ALMA.

13 Changes in organisation

[Module 1]

During 2021 a number of internal re-organisations were carried out affecting the OSO Division within the SEE department that hosts the OSO infrastructure activities. First the Space Geodesy unit left the OSO Division to for part of a new GEO Divison within SEE. The Space Geodesy unit remains however a key part of the OSO infrastructure managing its Geoscience activities. In addition to this two units within the OSO division covering respectively Electronic Lab/Workshop and Computer support activities were merged to form a new Technical Support Group (TSG).

During 2021 a new Onsala Steering Committee (OSC) was formed and held its first online meetings during Autumn 2021. The chair of the new OSC is Jan-Eric Sundgren with the full membership listed at http://www.chalmers.se/en/centres/oso/about-us/Pages/Organization.aspx). The above page also lists the current membership of the OSO Time Allocation Committee (evaluating APEX and 20 m telescope proposals) and the LOFAR-Sweden time allocations committee which provides input to the international LOFAR time allocation process.

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 education at all levels from bachelor to graduate studies at Chalmers, and through organised schools.

15 Importance to industry

Currently the major industrial impact of OSO's work is connected with 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 2021 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.

During 2021 Chalmers Level 1 leadership of the SKA1-mid Band 1 and SKA1-mid Digitizer work packages continued with involvement of the Quamcom company in the final industrial design of the SKA1.mid digitizers. In addition, preparations began for the selection of a Swedish company to act as the prime contractor for the delivery of the SKA1-mid Band 1 receiver package.

Acronyms

A&A	Astronomy & Astrophysics (a scientific journal)
ACA	Atacama Compact Array
AETHRA	Advanced European Technologies for Heterodyne Receivers for Astronomy (part of RadioNet)
AGB	Asymptotic Giant Branch (AGB stars are giant evolved stars)
AGN	Active Galactic Nucleus
AI	Artificial Intelligence
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
AU	Astronomical Unit (the distance between the Sun and Earth)
BRAND	BRoad bAND EVN (part of RadioNet)
C3SE	Chalmers Centre for Computational Science and Engineering
CEPT	European Conference of Postal and Telecommunications Administrations Correspondance Group
CIT	Chalmers Industrial Technology
CO	Carbon monoxide (molecule frequently observed by radio telescopes)
CRAF	Committee on Radio Astronomy Frequencies (ESF)
DBBC	Digital Base Band Converter (equipment for VLBI observations)
EAS	European Astronomical Society
EC	European Commission
ERIC	European Research Infrastructure Consortium
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)
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
HMXB	High-mass X-ray binary
HST	Hubble Space Telescope
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
ICRF	International Celestial Reference Frame
ICSU	International Council for Science
IERS	International Earth Rotation and Reference Frame Service
IF	Intermediate frequency
IGETS	International Geodynamics and Earth Tide Service
IGO	Inter-governmental organisation
IGS	The International GNSS Service
ILO	Industrial Liaison Officer
ILT	International LOFAR Telescope
IMBH	Intermediate mass black hole
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)
JRA	Joint Research Activity (part of RadioNet)
LOFAR	Low Frequency Array
LOFAR4SW	LOFAR for Space Weather (EU Horizon 2020 project)
mas	milliarcsecond
MC2	Department of Microtechnology and Nanoscience at Chalmers
ML	Machine Learning
MNRAS	Monthly Notices of the Royal Astronomical Society (a scientific journal)
MWA	Murchison Widefield Array
NDACC	Network for the Detection of Atmospheric Composition Change
NOVA	Nederlandse Onderzoekschool Voor Astronomie (The Netherlands Research School for Astronomy)
ODP	Observatory Development Programme (for SKA)
OSC	Onsala Steering Committee
OSO	Onsala Space Observatory
OTT	Onsala Twin Telescope
PI	Principal Investigator
RadioNet	Advanced Radio Astronomy in Europe (EU Horizon 2020 project)
RFI	Radio Frequency Interference
RINGS	Radio Interferometry Next Generation Software (part of RadioNet)
RISE	Research Institutes of Sweden
SALSA	Small antennas at OSO for education and outreach
SCG	Superconducting Gravimeter
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)
SKA	Square Kilometre Array
SKAO	Square Kilometre Array Organisation
SLR	Satellite Laser Ranging
SMBH	Supermassive black hole
SMHI	Sveriges meteorologiska och hydrologiska institut (Swedish Meteorological and Hydrological Institute)
SNIC	Swedish National Infrastructure for Computing
SNR	Signal-to-Noise Ratio
SNSN	Svenska nationella seismiska nätverket
SRC	SKA Regional Centre
SUNET	Swedish University Computer Network
SWEPOS	The Swedish permanent GNSS network, hosted by Lantmäteriet
TAC	Time Allocation Committee
TDE	Tidal Disruption Event
TEC	Total Electron Content
TG	Tide gauge
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
VINNOVA	Sweden's innovation agency
VLBA	Very Long Baseline Array
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)
WP	Work Package

Publications 2021

This section lists publications in refereed journals 2021 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 (90/65) *(Nordic/Swedish)*
  thereof with explicit Nordic ARC node support (30/26) *(Nordic/Swedish)*
- **APEX** observations (all APEX partners' observing time) (62/15) *(total/Swedish)*
- **Astronomical VLBI** obs. w. EHT, EVN or GMVA, or using JIVE (39/13) *(total/Swedish)*
- **LOFAR** observations (124/9) *(total/Swedish)*
- **Geoscience** (OSO instruments specifically stated) (29/10) *(total/Swedish)*
- **Onsala 20 m telescope, single-dish** observations (5/3) *(total/Swedish)*
- **Technical** publications about, e.g., receiver development, by OSO staff (9)

In addition to the publications listed below, in 2021 there was one publication using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), and 7 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 references 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
Astropart. Phys.	Astroparticle Physcis
JCAP	Journal of Cosmology and Astroparticle Physics
J. Geod.	Journal of Geodesy
JSTARS	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing
JSWSC	Journal of Space Weather and Space Climate
MNRAS	Monthly Notices of the Royal Astronomical Society
PASA	Publications of the Astronomical Society of Australia
PASP	Publications of the Astronomical Society of the Pacific
Phys. Rev. Lett.	Physical Review Letters
Publ. DGPF	Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation (DGPF) e.V.
ScienceA	Science Advances
Space Sci. Rev.	Space Science Reviews

ALMA,
publications in refereed journals 2021, with Nordic authors

Swedish authors (ALMA)

DEATHSTAR: nearby AGB stars with the Atacama Compact Array. II. CO envelope sizes and asymmetries: the S-type stars
Andriantsaralaza, M., Ramstedt, S., Vlemmings, W. H. T., Danilovich, T., De Beck, E., Groenewegen, M. A. T., Höfner, S., Kerschbaum, F., Khouri, T., Lindqvist, M., Maercker, M., Olofsson, H., Quintana-Lacaci, G., Saberi, M., Sahai, R., & Zijlstra, A.
A&A 653, A53 (2021)
10.1051/0004-6361/202140952

Black hole feeding and star formation in NGC 1808
Audibert, A., Combes, F., García-Burillo, S., Hunt, L., Eckart, A., Aalto, S., Casasola, V., Boone, F., Krips, M., Viti, S., Muller, S., Dasyra, K., van der Werf, P., & Martín, S.
A&A 656, A60 (2021)
10.1051/0004-6361/202039886

Accurate dust temperature determination in a z = 7.13 galaxy
Bakx, T. J. L. C., Sommovigo, L., Carniani, S., Ferrara, A., Akins, H. B., Fujimoto, S., Hagimoto, M., Knudsen, K. K., Pallottini, A., Tamura, Y., & Watson, D.
MNRAS 508, L58 (2021)
10.1093/mnrasl/slab104

ALMA-IRDC: dense gas mass distribution from cloud to core scales
Barnes, A. T., Henshaw, J. D., Fontani, F., Pineda, J. E., Cosentino, G., Tan, J. C., Caselli, P., Jiménez-Serra, I., Law, C. Y., Avison, A., Bigiel, F., Feng, S., Kong, S., Longmore, S. N., Moser, L., Parker, R. J., Sánchez-Monge, Á., & Wang, K.
MNRAS 503, 4601 (2021)
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Molecular gas kinematics in the nuclear region of nearby Seyfert galaxies with ALMA
Bewketu Belete, A., Andreani, P., Fernández-Ontiveros, J. A., Hatziminaoglou, E., Combes, F., Sirressi, M., Slater, R., Ricci, C., Dasyra, K., Cicone, C., Aalto, S., Spinoglio, L., Imanishi, M., & De Medeiros, J. R.
A&A 654, A24 (2021)
10.1051/0004-6361/202140492

A puzzling non-detection of [O III] and [C II] from a z ≈ 7.7 galaxy observed with ALMA
Binggeli, C., Inoue, A. K., Hashimoto, T., Toribio, M. C., Zackrisson, E., Ramstedt, S., Mawatari, K., Harikane, Y., Matsuo, H., Okamoto, T., Ota, K., Shimizu, I., Tamura, Y., Taniguchi, Y., & Umehata, H.
A&A 646, A26 (2021)
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An ALMA/NOEMA survey of the molecular gas properties of high-redshift star-forming galaxies
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A&A 645, A45 (2021)
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Caputi, K. I., Caminha, G. B., Fujimoto, S., Kohno, K., Sun, F., Egami, E., Deshmukh, S., Tang, F., Ao, Y., Bradley, L., Coe, D., Espada, D., Grillo, C., Hatsukade, B., Knudsen, K. K., Lee, M. M., Magdis, G. E., Morokuma-Matsui, K., Oesch, P., Ouchi, M., Rosati, P., Umehata, H., Valentino, F., Vanzella, E., Wang, W.-H., Wu, J. F., & Zitrin, A.
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Cheng, Y., Tan, J. C., Caselli, P., Fissel, L., Arce, H. G., Fontani, F., Goodson, M. D., Liu, M., & Galitzki, N.
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10.3847/1538-4357/abc9b0

ALMA and IRIS Observations of the Solar Chromosphere. I. An On-disk Type II Spicule
Chintzoglou, G., De Pontieu, B., Martínez-Sykora, J., Hansteen, V., de la Cruz Rodríguez, J., Szydlarski, M., Jafarzadeh, S., Wedemeyer, S., Bastian, T. S., & Sainz Dalda, A.
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da Cunha, E., Hodge, J. A., Casey, C. M., Algera, H. S. B., Kaasinen, M., Smail, I., Walter, F., Brandt, W. N., Dannerbauer, H., Decarli, R., Groves, B. A., Knudsen, K. K., Swinbank, A. M., Weiss, A., van der Werf, P., & Zavala, J. A.
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Danilovich, T., Van de Sande, M., Plane, J. M. C., Millar, T. J., Royer, P., Amor, M. A., Hammami, K., Decock, L., Gottlieb, C. A., Decin, L., Richards, A. M. S., De Beck, E., Baudry, A., Bolte, J., Cannon, E., De Ceuster, F., de Koter, A., Etoka, S., Gobrecht, D., Gray, M., Herpin, F., Homan, W., Jeste, M., Kervella, P., Khouri, T., Lagadec, E., Maes, S., Malfait, J., McDonald, I., Menten, K. M., Montargès, M., Müller, H. S. P., Pimpanuwat, B., Sahai, R., Wallström, S. H. J., Waters, L. B. F. M., Wong, K. T., Yates, J., & Zijlstra, A.
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Broadband Multi-wavelength Properties of M87 during the 2017 Event Horizon Telescope Campaign
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First M87 Event Horizon Telescope Results. VIII. Magnetic Field Structure near The Event Horizon
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First M87 Event Horizon Telescope Results. VII. Polarization of the Ring
Event Horizon Telescope Collaboration, Akiyama, K., Algaba, J. C., Alberdi, A., Alef, W., Anantua, R., Asada, K., Azulay, R., Baczko, A.-K., Ball, D., Balokovic, M., Barrett, J., Benson, B. A., Bintley, D., Blackburn, L., Blundell, R., Boland, W., Bouman, K. L., Bower, G. C., Boyce, H., Bremer, M., Brinkerink, C. D., Brissenden, R., Britzen, S., Broderick, A. E., Broguiere, D., Bronzwaer, T., Byun, D.-Y., Carlstrom, J. E., Chael, A., Chan, C.-. kwan., Chatterjee, S., Chatterjee, K., Chen, M.-T., Chen, Y., Chesler, P. M., Cho, I., Christian, P., Conway, J. E., Cordes, J. M., Crawford, T. M., Crew, G. B., Cruz-Osorio, A., Cui, Y., Davelaar, J., De Laurentis, M., Deane, R., Dempsey, J., Desvignes, G., Dexter, J., Doeleman, S. S., Eatough, R. P., Falcke, H., Farah, J., Fish, V. L., Fomalont, E., Ford, H. A., Fraga-Encinas, R., Freeman, W. T., Friberg, P., Fromm, C. M., Fuentes, A., Galison, P., Gammie, C. F., García, R., Gentaz, O., Georgiev, B., Goddi, C., Gold, R., Gómez, J. L., Gómez-Ruiz, A. I., Gu, M., Gurwell, M., Hada, K., Haggard, D., Hecht, M. H., Hesper, R., Ho, L. C., Ho, P., Honma, M., Huang, C.-W. L., Huang, L., Hughes, D. H., Ikeda, S., Inoue, M., Issaoun, S., James, D. J., Jannuzi, B. T., Janssen, M., Jeter, B., Jiang, W., Jimenez-Rosales, A., Johnson, M. D., Jorstad, S., Jung, T., Karami, M., Karuppusamy, R., Kawashima, T., Keating, G. K., Kettenis, M., Kim, D.-J., Kim, J.-Y., Kim, J., Kim, J., Kino, M., Koay, J. Y., Kofuji, Y.,

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Fuente, A., Treviño-Morales, S. P., Alonso-Albi, T., Sánchez-Monge, A., Rivière-Marichalar, P., & Navarro-Almaida, D.
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ALMA Lensing Cluster Survey: Bright [C II] 158 μm Lines from a Multiply Imaged Sub-L Galaxy at z = 6.0719*
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SUPER. V. ALMA continuum observations of z ∼ 2 AGN and the elusive evidence of outflows influencing star formation
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The Polarized Image of a Synchrotron-emitting Ring of Gas Orbiting a Black Hole
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Broadband Multi-wavelength Properties of M87 during the 2017 Event Horizon Telescope Campaign
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C., Kuo, C.-Y., Lauer, T. R., Levis, A., Li, Y.-R., Li, Z., Lindqvist, M., Lico, R., Lindahl, G., Liu, J., Liu, K., Liuzzo, E., Lo, W.-P., Lobanov, A. P., Loinard, L., Lonsdale, C., MacDonald, N. R., Mao, J., Marchili, N., Marrone, D. P., Marscher, A. P., Martí-Vidal, I., Matsushita, S., Matthews, L. D., Medeiros, L., Menten, K. M., Mizuno, I., Mizuno, Y., Moran, J. M., Moriyama, K., Moscibrodzka, M., Müller, C., Musoke, G., Mejías, A. M., Nagai, H., Nagar, N. M., Nakamura, M., Narayan, R., Narayanan, G., Natarajan, I., Nathanail, A., Neri, R., Ni, C., Noutsos, A., Okino, H., Olivares, H., Ortiz-León, G. N., Oyama, T., Özel, F., Palumbo, D. C. M., Patel, N., Pen, U.-L., Pesce, D. W., Piétu, V., Plambeck, R., Popstefanija, A., Porth, O., Pötzl, F. M., Prather, B., Preciado-López, J. A., Psaltis, D., Pu, H.-Y., Rao, R., Rawlings, M. G., Raymond, A. W., Rezzolla, L., Ricarte, A., Ripperda, B., Roelofs, F., Rogers, A., Ros, E., Rose, M., Roshanineshat, A., Rottmann, H., Roy, A. L., Ruszczyk, C., Rygl, K. L. J., Sánchez, S., Sánchez-Arguelles, D., Savolainen, T., Schloerb, F. P., Schuster, K.-F., Shao, L., Shen, Z., Small, D., Sohn, B. W., Soohoo, J., Sun, H., Tazaki, F., Tetarenko, A. J., Tiede, P., Tilanus, R. P. J., Titus, M., Toma, K., Torne, P., Trent, T., Traianou, E., Trippe, S., van Bemmel, I., van Langevelde, H. J., van Rossum, D. R., Wagner, J., Ward-Thompson, D., Wardle, J., Weintroub, J., Wex, N., Wharton, R., Wielgus, M., Wong, G. N., Wu, Q., Yoon, D., Young, A., Young, K., Younsi, Z., Yuan, F., Yuan, Y.-F., Zensus, J. A., Zhao, G.-Y., Zhao, S.-S., Fermi Large Area Telescope Collaboration, Principe, G., Giroletti, M., D'Ammando, F., Orienti, M., H. E. S. S. Collaboration, Abdalla, H., Adam, R., Aharonian, F., Benkhali, F. A., Angüner, E. O., Arcaro, C., Armand, C., Armstrong, T., Ashkar, H., Backes, M., Baghmanyan, V., Barbosa Martins, V., Barnacka, A., Barnard, M., Becherini, Y., Berge, D., Bernlöhr, K., Bi, B., Böttcher, M., Boisson, C., Bolmont, J., de Lavergne, M. D. B., Breuhaus, M., Brun, F., Brun, P., Bryan, M., Büchele, M., Bulik, T., Bylund, T., Caroff, S., Carosi, A., Casanova, S., Chand, T., Chen, A., Cotter, G., Curyło, M., Damascene Mbarubucyeye, J., Davids, I. D., Davies, J., Deil, C., Devin, J., Dewilt, P., Dirson, L., Djannati-Ataï, A., Dmytriiev, A., Donath, A., Doroshenko, V., Duffy, C., Dyks, J., Egberts, K., Eichhorn, F., Einecke, S., Emery, G., Ernenwein, J.-P., Feijen, K., Fegan, S., Fiasson, A., de Clairfontaine, G. F., Fontaine, G., Funk, S., Fü√üling, M., Gabici, S., Gallant, Y. A., Giavitto, G., Giunti, L., Glawion, D., Glicenstein, J. F., Gottschall, D., Grondin, M.-H., Hahn, J., Haupt, M., Hermann, G., Hinton, J. A., Hofmann, W., Hoischen, C., Holch, T. L., Holler, M., Hörbe, M., Horns, D., Huber, D., Jamrozy, M., Jankowsky, D., Jankowsky, F., Jardin-Blicq, A., Joshi, V., Jung-Richardt, I., Kasai, E., Kastendieck, M. A., Katarzy≈Ñski, K., Katz, U., Khangulyan, D., Khélifi, B., Klepser, S., Klu≈∫niak, W., Komin, N., Konno, R., Kosack, K., Kostunin, D., Kreter, M., Lamanna, G., Lemière, A., Lemoine-Goumard, M., Lenain, J.-P., Levy, C., Lohse, T., Lypova, I., Mackey, J., Majumdar, J., Malyshev, D., Malyshev, D., Marandon, V., Marchegiani, P., Marcowith, A., Mares, A., Martí-Devesa, G., Marx, R., Maurin, G., Meintjes, P. J., Meyer, M., Moderski, R., Mohamed, M., Mohrmann, L., Montanari, A., Moore, C., Morris, P., Moulin, E., Muller, J., Murach, T., Nakashima, K., Nayerhoda, A., de Naurois, M., Ndiyavala, H., Niederwanger, F., Niemiec, J., Oakes, L., O'Brien, P., Odaka, H., Ohm, S., Olivera-Nieto, L., de Ona Wilhelmi, E., Ostrowski, M., Panter, M., Panny, S., Parsons, R. D., Peron, G., Peyaud, B., Piel, Q., Pita, S., Poireau, V., Noel, A. P., Prokhorov, D. A., Prokoph, H., Pühlhofer, G., Punch, M., Quirrenbach, A., Rauth, R., Reichherzer, P., Reimer, A., Reimer, O., Remy, Q., Renaud, M., Rieger, F., Rinchiuso, L., Romoli, C., Rowell, G., Rudak, B., Ruiz-Velasco, E., Sahakian, V., Sailer, S., Sanchez, D. A., Santangelo, A., Sasaki, M., Scalici, M., Schutte, H. M., Schwanke, U., Schwemmer, S., Seglar-Arroyo, M., Senniappan, M., Seyffert, A. S., Shafi, N., Shiningayamwe, K., Simoni, R., Sinha, A., Sol, H., Specovius, A., Spencer, S., Spir-Jacob, M., Stawarz, Ł., Sun, L., Steenkamp, R., Stegmann, C., Steinmassl, S., Steppa, C., Takahashi, T., Tavernier, T., Taylor, A. M., Terrier, R., Tiziani, D., Tluczykont, M., Tomankova, L., Trichard, C., Tsirou, M., Tuffs, R., Uchiyama, Y., van der Walt, D. J., van Eldik, C., van

Rensburg, C., van Soelen, B., Vasileiadis, G., Veh, J., Venter, C., Vincent, P., Vink, J., Völk, H. J., Vuillaume, T., Wadiasingh, Z., Wagner, S. J., Watson, J., Werner, F., White, R., Wierzcholska, A., Wong, Y. W., Yusafzai, A., Zacharias, M., Zanin, R., Zargaryan, D., Zdziarski, A. A., Zech, A., Zhu, S. J., Zorn, J., Zouari, S., Zywucka, N., MAGIC Collaboration, Acciari, V. A., Ansoldi, S., Antonelli, L. A., Engels, A. A., Artero, M., Asano, K., Baack, D., Babic, A., Baquero, A., de Almeida, U. B., Barrio, J. A., Becerra González, J., Bednarek, W., Bellizzi, L., Bernardini, E., Bernardos, M., Berti, A., Besenrieder, J., Bhattacharyya, W., Bigongiari, C., Biland, A., Blanch, O., Bonnoli, G., Bo≈°njak, ≈Ω., Busetto, G., Carosi, R., Ceribella, G., Cerruti, M., Chai, Y., Chilingarian, A., Cikota, S., Colak, S. M., Colombo, E., Contreras, J. L., Cortina, J., Covino, S., D'Amico, G., D'Elia, V., da Vela, P., Dazzi, F., de Angelis, A., de Lotto, B., Delfino, M., Delgado, J., Delgado Mendez, C., Depaoli, D., di Pierro, F., di Venere, L., Do Souto Espiñeira, E., Dominis Prester, D., Donini, A., Dorner, D., Doro, M., Elsaesser, D., Ramazani, V. F., Fattorini, A., Ferrara, G., Fonseca, M. V., Font, L., Fruck, C., Fukami, S., García López, R. J., Garczarczyk, M., Gasparyan, S., Gaug, M., Giglietto, N., Giordano, F., Gliwny, P., Godinovic, N., Green, J. G., Green, D., Hadasch, D., Hahn, A., Heckmann, L., Herrera, J., Hoang, J., Hrupec, D., Hütten, M., Inada, T., Inoue, S., Ishio, K., Iwamura, Y., Jiménez, I., Jormanainen, J., Jouvin, L., Kajiwara, Y., Karjalainen, M., Kerszberg, D., Kobayashi, Y., Kubo, H., Kushida, J., Lamastra, A., Lelas, D., Leone, F., Lindfors, E., Lombardi, S., Longo, F., López-Coto, R., López-Moya, M., López-Oramas, A., Loporchio, S., Machado de Oliveira Fraga, B., Maggio, C., Majumdar, P., Makariev, M., Mallamaci, M., Maneva, G., Manganaro, M., Mannheim, K., Maraschi, L., Mariotti, M., Martínez, M., Mazin, D., Menchiari, S., Mender, S., Micanovic, S., Miceli, D., Miener, T., Minev, M., Miranda, J. M., Mirzoyan, R., Molina, E., Moralejo, A., Morcuende, D., Moreno, V., Moretti, E., Neustroev, V., Nigro, C., Nilsson, K., Nishijima, K., Noda, K., Nozaki, S., Ohtani, Y., Oka, T., Otero-Santos, J., Paiano, S., Palatiello, M., Paneque, D., Paoletti, R., Paredes, J. M., Pavletic, L., Peñil, P., Perennes, C., Persic, M., Moroni, P. G. P., Prandini, E., Priyadarshi, C., Puljak, I., Rhode, W., Ribó, M., Rico, J., Righi, C., Rugliancich, A., Saha, L., Sahakyan, N., Saito, T., Sakurai, S., Satalecka, K., Saturni, F. G., Schleicher, B., Schmidt, K., Schweizer, T., Sitarek, J., Snidaric, I., Sobczynska, D., Spolon, A., Stamerra, A., Strom, D., Strzys, M., Suda, Y., Suric, T., Takahashi, M., Tavecchio, F., Temnikov, P., Terzic, T., Teshima, M., Tosti, L., Truzzi, S., Tutone, A., Ubach, S., van Scherpenberg, J., Vanzo, G., Vazquez Acosta, M., Ventura, S., Verguilov, V., Vigorito, C. F., Vitale, V., Vovk, I., Will, M., Wunderlich, C., Zaric, D., VERITAS Collaboration, Adams, C. B., Benbow, W., Brill, A., Capasso, M., Christiansen, J. L., Chromey, A. J., Daniel, M. K., Errando, M., Farrell, K. A., Feng, Q., Finley, J. P., Fortson, L., Furniss, A., Gent, A., Giuri, C., Hassan, T., Hervet, O., Holder, J., Hughes, G., Humensky, T. B., Jin, W., Kaaret, P., Kertzman, M., Kieda, D., Kumar, S., Lang, M. J., Lundy, M., Maier, G., Moriarty, P., Mukherjee, R., Nieto, D., Nievas-Rosillo, M., O'Brien, S., Ong, R. A., Otte, A. N., Patel, S., Pfrang, K., Pohl, M., Prado, R. R., Pueschel, E., Quinn, J., Ragan, K., Reynolds, P. T., Ribeiro, D., Richards, G. T., Roache, E., Rulten, C., Ryan, J. L., Santander, M., Sembroski, G. H., Shang, R., Weinstein, A., Williams, D. A., Williamson, T. J., Eavn Collaboration, Hirota, T., Cui, L., Niinuma, K., Ro, H., Sakai, N., Sawada-Satoh, S., Wajima, K., Wang, N., Liu, X., & Yonekura, Y.
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First M87 Event Horizon Telescope Results. VIII. Magnetic Field Structure near The Event Horizon
Event Horizon Telescope Collaboration, Akiyama, K., Algaba, J. C., Alberdi, A., Alef, W., Anantua, R., Asada, K., Azulay, R., Baczko, A.-K., Ball, D., Balokovic, M., Barrett, J.,

Benson, B. A., Bintley, D., Blackburn, L., Blundell, R., Boland, W., Bouman, K. L., Bower, G. C., Boyce, H., Bremer, M., Brinkerink, C. D., Brissenden, R., Britzen, S., Broderick, A. E., Broguiere, D., Bronzwaer, T., Byun, D.-Y., Carlstrom, J. E., Chael, A., Chan, C.-. kwan., Chatterjee, S., Chatterjee, K., Chen, M.-T., Chen, Y., Chesler, P. M., Cho, I., Christian, P., Conway, J. E., Cordes, J. M., Crawford, T. M., Crew, G. B., Cruz-Osorio, A., Cui, Y., Davelaar, J., De Laurentis, M., Deane, R., Dempsey, J., Desvignes, G., Dexter, J., Doeleman, S. S., Eatough, R. P., Falcke, H., Farah, J., Fish, V. L., Fomalont, E., Ford, H. A., Fraga-Encinas, R., Friberg, P., Fromm, C. M., Fuentes, A., Galison, P., Gammie, C. F., García, R., Gelles, Z., Gentaz, O., Georgiev, B., Goddi, C., Gold, R., Gómez, J. L., Gómez-Ruiz, A. I., Gu, M., Gurwell, M., Hada, K., Haggard, D., Hecht, M. H., Hesper, R., Himwich, E., Ho, L. C., Ho, P., Honma, M., Huang, C.-W. L., Huang, L., Hughes, D. H., Ikeda, S., Inoue, M., Issaoun, S., James, D. J., Jannuzi, B. T., Janssen, M., Jeter, B., Jiang, W., Jimenez-Rosales, A., Johnson, M. D., Jorstad, S., Jung, T., Karami, M., Karuppusamy, R., Kawashima, T., Keating, G. K., Kettenis, M., Kim, D.-J., Kim, J.-Y., Kim, J., Kim, J., Kino, M., Koay, J. Y., Kofuji, Y., Koch, P. M., Koyama, S., Kramer, M., Kramer, C., Krichbaum, T. P., Kuo, C.-Y., Lauer, T. R., Lee, S.-S., Levis, A., Li, Y.-R., Li, Z., Lindqvist, M., Lico, R., Lindahl, G., Liu, J., Liu, K., Liuzzo, E., Lo, W.-P., Lobanov, A. P., Loinard, L., Lonsdale, C., Lu, R.-S., MacDonald, N. R., Mao, J., Marchili, N., Markoff, S., Marrone, D. P., Marscher, A. P., Martí-Vidal, I., Matsushita, S., Matthews, L. D., Medeiros, L., Menten, K. M., Mizuno, I., Mizuno, Y., Moran, J. M., Moriyama, K., Moscibrodzka, M., Müller, C., Musoke, G., Mus Mejías, A., Michalik, D., Nadolski, A., Nagai, H., Nagar, N. M., Nakamura, M., Narayan, R., Narayanan, G., Natarajan, I., Nathanail, A., Neilsen, J., Neri, R., Ni, C., Noutsos, A., Nowak, M. A., Okino, H., Olivares, H., Ortiz-León, G. N., Oyama, T., Özel, F., Palumbo, D. C. M., Park, J., Patel, N., Pen, U.-L., Pesce, D. W., Piétu, V., Plambeck, R., PopStefanija, A., Porth, O., Pötzl, F. M., Prather, B., Preciado-López, J. A., Psaltis, D., Pu, H.-Y., Ramakrishnan, V., Rao, R., Rawlings, M. G., Raymond, A. W., Rezzolla, L., Ricarte, A., Ripperda, B., Roelofs, F., Rogers, A., Ros, E., Rose, M., Roshanineshat, A., Rottmann, H., Roy, A. L., Ruszczyk, C., Rygl, K. L. J., Sánchez, S., Sánchez-Arguelles, D., Sasada, M., Savolainen, T., Schloerb, F. P., Schuster, K.-F., Shao, L., Shen, Z., Small, D., Sohn, B. W., SooHoo, J., Sun, H., Tazaki, F., Tetarenko, A. J., Tiede, P., Tilanus, R. P. J., Titus, M., Toma, K., Torne, P., Trent, T., Traianou, E., Trippe, S., van Bemmel, I., van Langevelde, H. J., van Rossum, D. R., Wagner, J., Ward-Thompson, D., Wardle, J., Weintroub, J., Wex, N., Wharton, R., Wielgus, M., Wong, G. N., Wu, Q., Yoon, D., Young, A., Young, K., Younsi, Z., Yuan, F., Yuan, Y.-F., Zensus, J. A., Zhao, G.-Y., & Zhao, S.-S.
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First M87 Event Horizon Telescope Results. VII. Polarization of the Ring
Event Horizon Telescope Collaboration, Akiyama, K., Algaba, J. C., Alberdi, A., Alef, W., Anantua, R., Asada, K., Azulay, R., Baczko, A.-K., Ball, D., Balokovic, M., Barrett, J., Benson, B. A., Bintley, D., Blackburn, L., Blundell, R., Boland, W., Bouman, K. L., Bower, G. C., Boyce, H., Bremer, M., Brinkerink, C. D., Brissenden, R., Britzen, S., Broderick, A. E., Broguiere, D., Bronzwaer, T., Byun, D.-Y., Carlstrom, J. E., Chael, A., Chan, C.-. kwan., Chatterjee, S., Chatterjee, K., Chen, M.-T., Chen, Y., Chesler, P. M., Cho, I., Christian, P., Conway, J. E., Cordes, J. M., Crawford, T. M., Crew, G. B., Cruz-Osorio, A., Cui, Y., Davelaar, J., De Laurentis, M., Deane, R., Dempsey, J., Desvignes, G., Dexter, J., Doeleman, S. S., Eatough, R. P., Falcke, H., Farah, J., Fish, V. L., Fomalont, E., Ford, H. A., Fraga-Encinas, R., Freeman, W. T., Friberg, P., Fromm, C. M., Fuentes, A., Galison, P., Gammie, C. F., García, R., Gentaz, O., Georgiev, B., Goddi, C., Gold, R., Gómez, J. L., Gómez-Ruiz, A. I., Gu, M., Gurwell, M., Hada, K., Haggard, D., Hecht, M. H., Hesper, R., Ho, L. C., Ho, P.,

Honma, M., Huang, C.-W. L., Huang, L., Hughes, D. H., Ikeda, S., Inoue, M., Issaoun, S., James, D. J., Jannuzi, B. T., Janssen, M., Jeter, B., Jiang, W., Jimenez-Rosales, A., Johnson, M. D., Jorstad, S., Jung, T., Karami, M., Karuppusamy, R., Kawashima, T., Keating, G. K., Kettenis, M., Kim, D.-J., Kim, J.-Y., Kim, J., Kim, J., Kino, M., Koay, J. Y., Kofuji, Y., Koch, P. M., Koyama, S., Kramer, M., Kramer, C., Krichbaum, T. P., Kuo, C.-Y., Lauer, T. R., Lee, S.-S., Levis, A., Li, Y.-R., Li, Z., Lindqvist, M., Lico, R., Lindahl, G., Liu, J., Liu, K., Liuzzo, E., Lo, W.-P., Lobanov, A. P., Loinard, L., Lonsdale, C., Lu, R.-S., MacDonald, N. R., Mao, J., Marchili, N., Markoff, S., Marrone, D. P., Marscher, A. P., Martí-Vidal, I., Matsushita, S., Matthews, L. D., Medeiros, L., Menten, K. M., Mizuno, I., Mizuno, Y., Moran, J. M., Moriyama, K., Moscibrodzka, M., Müller, C., Musoke, G., Mejías, A. M., Michalik, D., Nadolski, A., Nagai, H., Nagar, N. M., Nakamura, M., Narayan, R., Narayanan, G., Natarajan, I., Nathanail, A., Neilsen, J., Neri, R., Ni, C., Noutsos, A., Nowak, M. A., Okino, H., Olivares, H., Ortiz-León, G. N., Oyama, T., Özel, F., Palumbo, D. C. M., Park, J., Patel, N., Pen, U.-L., Pesce, D. W., Piétu, V., Plambeck, R., PopStefanija, A., Porth, O., Pötzl, F. M., Prather, B., Preciado-López, J. A., Psaltis, D., Pu, H.-Y., Ramakrishnan, V., Rao, R., Rawlings, M. G., Raymond, A. W., Rezzolla, L., Ricarte, A., Ripperda, B., Roelofs, F., Rogers, A., Ros, E., Rose, M., Roshanineshat, A., Rottmann, H., Roy, A. L., Ruszczyk, C., Rygl, K. L. J., Sánchez, S., Sánchez-Arguelles, D., Sasada, M., Savolainen, T., Schloerb, F. P., Schuster, K.-F., Shao, L., Shen, Z., Small, D., Sohn, B. W., SooHoo, J., Sun, H., Tazaki, F., Tetarenko, A. J., Tiede, P., Tilanus, R. P. J., Titus, M., Toma, K., Torne, P., Trent, T., Traianou, E., Trippe, S., van Bemmel, I., van Langevelde, H. J., van Rossum, D. R., Wagner, J., Ward-Thompson, D., Wardle, J., Weintroub, J., Wex, N., Wharton, R., Wielgus, M., Wong, G. N., Wu, Q., Yoon, D., Young, A., Young, K., Younsi, Z., Yuan, F., Yuan, Y.-F., Zensus, J. A., Zhao, G.-Y., & Zhao, S.-S.
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Polarimetric Properties of Event Horizon Telescope Targets from ALMA
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Heterodyne Array receivers for Space and Ground Based Applications
Wiedner, M. C., A. Cooray, M. Gerin, D. Leisawitz, M. Meixner, A. Baryshev, V. Belitsky, V. Desmaris, A. DiGiorgi, J. D. Gallego, P. Goldsmith, F. Helmich, W. Jellema, A. Laurens, I. Mehdi, C. Risacher, Origins Science and Technology Definition Team, HERO team
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Heterodyne Receiver for Origins
Wiedner, M. C., S. Aalto, E. G Amatucci, A. M Baryshev, C. Battersby, V. Y Belitsky, E. Bergin, B. Borgo, R. C Carter, E. Caux, A. Cooray, J. A Corsetti, E. De Beck, Y. Delorme, V. Desmaris, M. J DiPirro, B. N Ellison, A. M. Di Giorgio, M. J Eggens, J. D. Gallego-Puyol, M. Gerin, P. F Goldsmith, C. Goldstein, F.P Helmich, F. Herpin, R. E Hills, M. Hogerheijde, L. K Hunt, W. Jellema, G. Keizer, J.-M. Krieg, G. Kroes, P. Laporte, A. Laurens, D. T Leisawitz, D. C Lis, G. E Martins, I. Mehdi, M. Meixner, G. J Melnick, S. N Milam, D. A Neufeld, N. Nguyen Tuong, R. Plume, K. Pontoppidan, B. Quertier-Dagorn, C. Risacher, J. G Staguhn, E. Tong, S. Viti, F. Wyrowski, Origins Space Telescope Mission Concept Study Team
Journal of Astronomical Telescopes, Instruments, and Systems 7, 011007 (2021)
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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: 2021

Katergorier av nyckelta
1 Anställda (enskilda individer eller FT
2 Projekt (representerade av en PI
3 Användare (enskilda individer
4 Kvantitet av användning
5 Output

1	Anställda vid infrastrukture	
1.1	*Enskilda individe*	
	Totalt	47
	Astro user support / ARCnode (Modul	6
	APEX svensk tid (Modul :	3
	Astronomisk VLBI (Modul 4	5
	LOFAR (Modul 5)	2
	Geovetenskap (Modul 6)	9
	Utveckling av mm-mottagare (Modul 8)	9
	Utveckling av cm-mottagare (Modul 9)	6
	Ledning (Modul 1)	3
	Övriga tjänster (Modul 1C	4
1.2	*FTE*	
	Totalt	31,7
	Astro user support / ARCnode (Modul	4,3
	APEX svensk tid (Modul :	2,7
	Astronomisk VLBI (Modul 4	3,4
	LOFAR (Modul 5)	0,8
	Geovetenskap (Modul 6)	4,7
	Utveckling av mm-mottagare (Modul 8)	6,8
	Utveckling av cm-mottagare (Modul 9)	3,9
	Ledning (Modul 1)	1,9
	Övriga tjänster (Modul 1C	3,3

Förklaringar till tabell 2, 3 och

ALMA: Tabell 2: Projekt med en nordisk PI. Cycle 7 (observationer oktober 2019 - september 2021*). Genomförda = projekt med minst ett levererat data
*Cycle 7 förlängdes till 2 år i stället för det vanliga 1 år p.g.a. pandemin. DDT-proposaler (DDT = Directors Discretionary Time) är inte medräknade i statistiken
Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle
Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal pro
APEX: Alla projekt på svensk tid. Sökta projekt för perioderna P108 och P1(
Astronomisk VLBI: Alla proposaler inskickade 2021. Alla observationer utförda 20:
LOFAR: Alla projekt i Cycle 16 och 17 (observationer november 2020 - november 202

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

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

Gråmarkerade fält är inte aktuella för OSO

		a. Alla projek			b. Typ av hemvist för alla P						c. Typ av akademisk hemvist för PI (endast akademiska hemvister		
					Akademisk			Kommersiel	Offentlig	Övriga			
2	Projekt	Totalt	Män	Kvinnor	Totalt	Män	Kvinnor	Totalt	Totalt	Totalt	Chalmers	Annat svenskt lärosät	Internationel
2.1	*Sökta projekt*												
	Totalt	263	179	84	263	179	84				76	8	179
	ALMA (projekt med nordisk PI	94	59	35	94	59	35				57	5	32
	APEX svensk ti	41	26	15	41	26	15				15	1	25
	Astronomisk VLB	83	64	19	83	64	19				4	0	79
	LOFAR	45	30	15	45	30	15				0	2	43
2.2	*Genomförda projekt*												
	Totalt	135	91	44	135	91	44				16	1	118
	ALMA (projekt med nordisk PI	14	10	4	14	10	4				7	0	7
	APEX svensk ti	27	14	13	27	14	13				9	0	18
	Astronomisk VLB	64	42	22	64	42	22				0	0	64
	LOFAR	30	25	5	30	25	5				0	1	29

3	Användare	d. Alla användare Totalt	Män	Kvinnor	e. Typ av hemvist för alla användare: Akademisk Totalt	Män	Kvinnor	Kommersiel Totalt	Offentlig Totalt	Övriga Totalt	f. Typ av akademisk hemvist för användare (endast akad. hemvister): Chalmers	Annat svenskt lärosäte	Internationel
3.1	*Sökta projekt*												
	Totalt	752	560	192	752	560	192				48	13	691
	ALMA (nordiska användare, alla projekt	130	90	40	130	90	40				37	28	65
	APEX svensk tid	128	89	39	128	89	39				25	4	99
	Astronomisk VLB	353	279	74	353	279	74				6	0	347
	LOFAR	269	197	72	269	197	72				3	3	263
3.2	*Genomförda projekt*												
	Totalt	676	491	185	676	491	185				51	19	606
	ALMA (nordiska användare, alla projekt	66	46	20	66	46	20				23	11	32
	APEX svensk tid	94	64	30	94	64	30				24	1	69
	Astronomisk VLB	347	254	93	347	254	93				3	4	340
	LOFAR	223	170	53	223	170	53				3	3	217

4	Typ och kvantitet av tillgång	g. Total kvantitet per typ av tillgång till infrastrukturen: Alla användare Fysisk	Data	Prover	h. Kvantitet av tillgång för akademiska projekt: Fysisk tillgång till infrastruktur Totalt	Män	Kvinnor
4.1	*Användning under året*						
	Totalt	n/a			n/a	n/a	n/a
	ALMA (antal projekt med nordisk P	14	20613 GB		14	10	4
	APEX svensk tid (h	387	14275 records		387	151	236
	Astronomisk VLBI (h	1816	801 TB/46.4 TB		1816	1380	436
	LOFAR (h)	2899	3.9 PB/1.5 PB		2899	2726	173
	Geodetisk VLBI (h)	2074			2074	n/a	n/a

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