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## Report on the activities in 2018 of

# Onsala Space Observatory

## The Swedish National Infrastructure for Radio Astronomy

This report presents the activities at Onsala Space Observatory (OSO) during 2018, 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.

*One antenna of the Onsala Twin Telescope (OTT) for geodetic VLBI with the radome of the 20 m telescope in the background. During 2018 the OTT became operational within the VLBI Global Observing System (VGOS) and now contributes regularly to the global network observations.*

Onsala, 15th April 2019

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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 OSOs March 2017 infrastructure proposal to VR. A financial account will be provided separately to VR.



# 1 Operations

During 2018 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 not part of VR funded national infrastructure activities but 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 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]*

In general, all telescopes have operated according to the 2018 activity plan without any major problems, more details are given below:

- **Onsala 20 m telescope:** The 20 m telescope was used in accordance with the 2018 activity plan without any major divergence. As anticipated, there were some reductions in the amount of geodetic experiments and PI project times due to the planned maintenance on the subreflector and the rebuilding of the control room. 36 geodetic 24-hour campaigns, 11 astronomical single-dish projects, participation in 5 extended astronomical VLBI sessions, 4 short VLBI out-of-session observations, and 3 teaching/outreach observations were still carried out. Apart from maintenance (incl. technical observations) at normal levels, considerable time was spent on installing and characterising the new subreflector mechanics/sensors, not only to verify functionality but to prepare for future upgrades of the X/Y/Z-focus and tilt models that the new hardware will allow. A few days of observations were spent on characterising the continuum sensitivity at 22 and 86 GHz. The new telescope control system Bifrost was successfully tried out in non-mapping science projects with local participants, but improvements were still being added throughout the year which required some telescope time for tests.

- **Onsala 25 m telescope:** The Onsala 25 m telescope has operated according to the 2018 activity plan without any major problems during the year.

- **APEX:** A total of 27 days, organized in three runs, of Swedish APEX observations were carried out in 2018. To perform service mode observations, which are organized as three observing shifts per day (afternoon, night, morning), OSO typically sends four observers per run. A major upgrade (new panels, subreflector, hexapod, wobbler) of the telescope was finished in 2018 including the installation and commissioning of the new dual sideband SEPIA660 receiver. Further panel improvements are expected in 2019.

- **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 Local mode, the station is controlled by OSO, and this observing time is partially allocated via an 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 as part of international networks of telescopes. The astronomical VLBI observations were scheduled based on recommendations from time allocation committees [the European VLBI Network TAC and the Global Millimetre VLBI Array (GMVA) TAC and for APEX the Event Horizon Telescope]. The International VLBI Service (IVS) scheduled the geodetic VLBI observations for Astrometry and Geodesy.

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

| | |
|---|---|
| – The Onsala 20 m telescope: | 40 days of astronomical VLBI |
| | 36 days of geodetic VLBI |
| | 45 days of single-dish astronomy |
| – The Onsala 25 m telescope: | 51 days of astronomical VLBI |
| – The LOFAR station: | 233 days (ILT), 131 days (local) |
| – APEX telescope | 27 days of single-dish astronomy on Swedish time. |

Note that time for "normal" technical service, pointing, etc. are not included in the above figures. These service activities amounted to about 16 and 14 days on the 20 m and 25 m telescopes, respectively. Test and commissioning observations that are not related to routine maintenance and repairs are not included.

## 1.2 Nordic ARC node

*[Module 2]*

In 2018, the Nordic ALMA Regional Centre (ARC) node provided support to the Nordic ALMA communities for data reduction and analysis of ALMA data from all observing cycles. Additionally, proposal preparation visits to the major Nordic astronomy institutes were organized for the Cycle 6 call for proposals (deadline 19 April 2018) to provide individual support on projects.

In Cycle 6, 68 % of all (71) proposals with Swedish co-I/PIs were awarded time. Swedish co-I/PI are represented on 88 out of a total of 661 accepted ALMA proposals. The Nordic ARC node provides contact scientists for each project with a Nordic PI or leading Nordic co-I. In 2018, contact scientists were assigned for 39 projects, plus continued support for five Cycle 5 projects that were carried over. The Cycle 6 support includes continued support for one of the four accepted Large Programs in Cycle 5. The contact scientists serve as the point of contact between the user and the ALMA project during the phase 2 scheduling block (SB) generation and afterwards. Nordic ARC node staff also supported 18 face-to-face visits for Nordic researchers for data reduction of ALMA projects, including archive research. Each project has taken an average of two weeks of full-time support. As quality assessment of standard projects is increasingly done through pipeline calibration and review at the Joint ALMA Observatory (JAO) in Chile, the Nordic ARC node performed quality assessment on primarily non-standard projects. During 2018 the Nordic ARC node processed a total of 16 quality assessment assignments, of which 12 were polarisation projects and the remaining 4 were other non-standard observations, such as high-frequency data and/or long baselines. All of these processed SBs were for Nordic projects.

In March, the ARC node manager and deputy manager attended the ARC node representatives face-to-face meeting in Bologna. During these annual meetings, the ARC node representatives discuss the status of the different nodes, operations of ALMA, and procedures for the upcoming ALMA deadline. In September, the ARC node participated in the annual all-hands meeting of the European ARC node members in the Czech Republic. At these annual meetings, all issues related to e.g. quality assessment, face-to-face support, ALMA operations and data reduction, which are of relevance for functioning of the ARC network, were discussed with all ARC nodes staff.

The Nordic ARC node continued the development and maintenance of the Advanced Data Analysis Tools, published at the Nordic ARC node webpage (http://www.oso.nordic-alma.se/software-tools.php). The modelling engine in UVMULTIFIT is being used for the

development of advanced calibration algorithms, in the frame of the RadioNet's (H2020) working package RINGS (Radio Interferometry Next Generation Software).

In addition, the Nordic node has started the development of a new diagnostic tool which will allow users to get an overview of the quality of their data, possible issues with the delivered data, and advise on how to optimally process and analyse the data. In particular with the majority of all data being processed through the pipeline, a tool that gives users a comprehensive overview of the critical aspects of the delivered data is essential.

Finally, the Nordic ARC node recruited two new staff in order to ensure continued, high-quality face-to-face support, the quality assessment of non-standard projects, and to support the development of software tools. In addition to these new staff one existing staff member left the ARC node, and their employment at OSO/Chalmers, during 2018.

### 1.3 Geophysical instruments

*[Module 6]*

The geodetic VLBI observing sessions, using the 20 m telescope with its S/X receiver system, are 24 h long and include regular IVS sessions in the R1-, RD-, RDV-, T2- and EUR-series. In total 36 sessions in the IVS program were observed during 2018, less than in previous years. The reason for this reduced number of observing sessions was that the observatory control room was renovated/rebuilt during the summer (June-August). 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.

Concerning the next generation geodetic VLBI, also called VGOS, we used the Onsala twin telescopes (OTT) for 15 international broadband VGOS sessions of 24 h duration each, and additionally for 10 European broadband VGOS sessions of 4 h duration each. Primarily, the North-eastern telescope was used (ONSA13NE) during these sessions, but for some of the sessions both OTT telescopes were used in parallel. All data were recorded with the corresponding DBBC3 backends in vdif-format on a dedicated FlexBuff recorder for the OTT. The international VGOS sessions were correlated at the MIT/Haystack correlator while the European VGOS sessions were correlated at the Bonn correlator. All data were transferred electronically. We also successfully observed a number of test sessions with our Japanese colleagues, using the Japanese VGOS setup.

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

- **GNSS stations:** OSO's primary GNSS station, called ONSA, has been operated continuously during 2018. It is a station in the SWEPOS network operated by Lantmäteriet. It 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 (more details in Sect. 2.2). During the last years, additionally a GNSS-based test network has been established at Onsala. The network is collocated with the Onsala VLBI (Very Long Baseline Interferometry) antennas and surrounding the area where a new Onsala twin telescopes (OTT) have been built. Six good locations for permanent GNSS installations were previously identified, and five of these have been equipped with steel-grid masts serving as monuments for permanent GNSS installations. The purpose is both to improve the knowledge of the station-dependent effects in SWEPOS, and to quantify these by analyzing the collected observational data. In addition, this network also serves as a monitoring tool for the local deformation around the new twin telescope. During 2018 also the sixth station has been established, OTT5, and

data recording started. OTT5 is intended to be the yet another important contribution to International GNSS Service (IGS).

- **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, which happens on average one to three times per year. Its primary instrument is a superconducting gravimeter (SCG, model GWR 054). This instrument has been operated with very few breaks in recording (less than 10 days) since its installation in June 2009.

- **Tide gauges:** The super tide gauge continued to acquire data with one minute temporal resolution over the year. It is one of the stations in the national observational network operated by the 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 GPS and GLONASS code- and carrier-phase observations as well as signal-to-noise ratio (SNR) measurements.

- **Water Vapour Radiometers:** The two water vapour radiometers, Astrid and Konrad, measure the sky brightness temperatures at 21 GHz and 31 GHz from which the radio wave propagation delay in the atmosphere is inferred. During 2018 they were both operating continuously with some data loss (< 5 %) in addition to the data acquired during rain which are not sufficiently accurate for our application of measuring effects from atmospheric water vapour and cloud liquid on signal propagation

- **Aeronomy station:** The aeronomy station has two radiometers. The single sideband $H_2O$ system (water vapour) measures the sky brightness temperature at 22 GHz and the double sideband $CO/O_3$ system (carbon monoxide and ozone) measures the sky brightness temperatures at 111 and 115 GHz. The spectra from both systems are used to retrieve vertical profiles of the observed molecules in the middle atmosphere. During 2018 350 days of $H_2O$ and 330 days of $CO/O_3$ measurements were collected.

- **Seismometer station:** OSO hosts a seismograph station in the Svenska nationella seismiska nätverket (SNSN) at 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 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.

# 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.

We note that for ALMA, APEX, astronomical VLBI, and LOFAR taken together, about 46 % of the Swedish users (individuals) were from other institutions than Chalmers. The Swedish non-Chalmers users were affiliated with Stockholm University, Uppsala University, the Royal Institute of Technology, the Royal Swedish Academy of Sciences, and Nordita.

About 30 % of the users in 2018 were women. There is no clear 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 publications:**

The list below give the *number of papers in refereed journals published in 2018*. Conference publications are not included. Two figures are given: total number of publications/number of publications with at least one Swedish author. For APEX, publications based on all partners' observing time are counted, because OSO contributes to the full APEX operations and because Swedish receivers are used by all partners. For ALMA, the numbers of publications with at least one Nordic author are given (the ARC node at Onsala assists scientists from all Nordic countries). The numbers for astronomical VLBI includes observations with EVN and GMVA, and use of JIVE. Publications by OSO staff on technical R&D are also counted. A publication list is found at the end of this report.

- ALMA 69/42 *(total/Swedish)*
- APEX 78/14
- Astronomical VLBI 20/4
- LOFAR 58/13
- Geoscience instruments 27/4
- 20 m telescope, single-dish 4/1
- Technical publ. by OSO staff -/6

***In addition***, in 2018 there was *one* publication using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), and *four* publications using data from *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) and key numbers for them are therefore not given in the tables at the end of this report. We note that in 2018, there were proposals for seven projects, out of which five were observed. There were six female and 13 male users on the observed projects. Of these, five were Swedish (all from Chalmers).

## 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 4 papers with one or more Swedish authors and 23 papers with non-Swedish authors published during 2018 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 36 experiments, each one with a length of 24 h and rather evenly spread over the year, were carried out during 2018 with the Onsala 20 telescope. Additionally, we have been observing with the Onsala twin telescopes during several VGOS sessions, both international (15 sessions, 24 h each) and European (10 sessions, 4 h each) ones.

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, 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, 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. It shall 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 of the users are found in the research community where GNSS data typically 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. During 2018 a new GNSS station called OSOI has been taken into operation. It is part of ESA's ionospheric monitor network.

*Gravimeter Laboratory:*
Gravimeter data with one-second samples and maximum with a two-minutes latency is publically 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 2018 one visit with an absolute gravimeter, Lantmäteriet's FG5, took place. The gravimeter was upgraded also to achieve higher bandwidth.

*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. In 2018 a new Greens functions for an anelastic Earth based on PREM assuming a flat Q-factor spectrum was added in the ocean loading provider. Also the provision of tilt parameters was added.

*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 2018 OSO collected about 350 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 2018 OSO has collected about 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. Swedish authors are underlined.

## *Astronomy*

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

### 3.1 ALMA

*[Module 2]*

***High-resolution observations of the symbiotic system R Aqr. Direct imaging of the gravitational effects of the secondary on the stellar wind***
Bujarrabal, V.; Alcolea, J.; Mikołajewska, J.; Castro-Carrizo, A.; Ramstedt, S.
Astronomy & Astrophysics 616, L3 (2018)
and
***CO envelope of the symbiotic star R Aquarii seen by ALMA***
Ramstedt, S.; Mohamed, S.; Olander, T.; Vlemmings, W. H. T.; Khouri, T.; Liljegren, S.
Astronomy & Astrophysics 616, A61 (2018)
*Summary (both papers above):* Symbiotic stars are identified through their composite spectra and are usually a binary pair with one hotter and one cooler, mass-losing companion. R Aqr is the closest and most well-studied symbiotic star. It is one of few symbiotics where the binary pair has been spatially resolved and the orbital parameters are somewhat constrained. The orbital period is about 40 years and the semi-major axis is estimated to 15.5 AU.

R Aqr is the smallest separation source in a sample of binary AGB stars for which the circumstellar CO($J$=3-2) have been mapped with ALMA in order to study the wind shaping due to the companion. With a resolution of about 0.5" the CO distribution is not well resolved, the total extent is less than 2", and clearly limited by the hot radiation in the system. The molecular envelope is confined to the equatorial plane and, as also confirmed by higher-resolution observations, consistent with what is expected from hydrodynamical wind-interaction models. Additional emission lines are also detected and several show inverse P-Cygni profiles consistent with infalling material close to the star, Fig. 3.1.

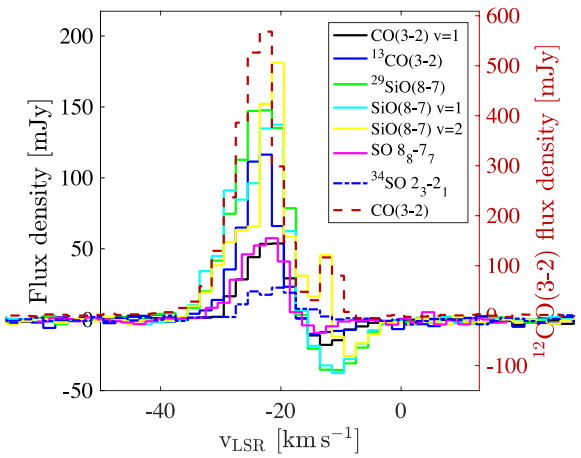



***Figure 3.1.*** *Molecular lines detected towards R Aqr with ALMA (Ramstedt et al. 2018).*

***Core Emergence in a Massive Infrared Dark Cloud: A Comparison between Mid-IR Extinction and 1.3 mm Emission***

Kong, Shuo; Tan, Jonathan C.; Arce, Héctor G.; Caselli, Paola; Fontani, Francesco; Butler, Michael J.

The Astrophysical Journal Letters 855, L25 (2018)

*Summary:* This paper presents part of the results from a large ALMA study (an 86-pointing mosaic) of a massive (about 100,000 solar mass), early-stage protocluster, which is revealed as an Infrared Dark Cloud (IRDC). The 1.3 mm dust continuum emission image is presented (Fig. 3.2) which reveals the presence of dense cores that are the localized sites of star formation within the cloud. The particular goal of this study was to compare the dust continuum emission cores with a mid-IR extinction map of the cloud, which Kong et al. (2018) consider to be a more accurate measure of the mass surface density of material in the structure. They searched for correlations of the presence of a core with local IRDC mass surface density. The data help define a core detection probability function, which rises from near zero at lower mass surface densities to near unity at high values, i.e., near 0.5 g/cm$^2$. This information helps constrain theories of star formation. Overall the results can be used to show that about 10 % of the gas in the IRDC is being converted into stars every local free-fall time, which is an elevated rate compared to most other molecular clouds in the Galaxy.

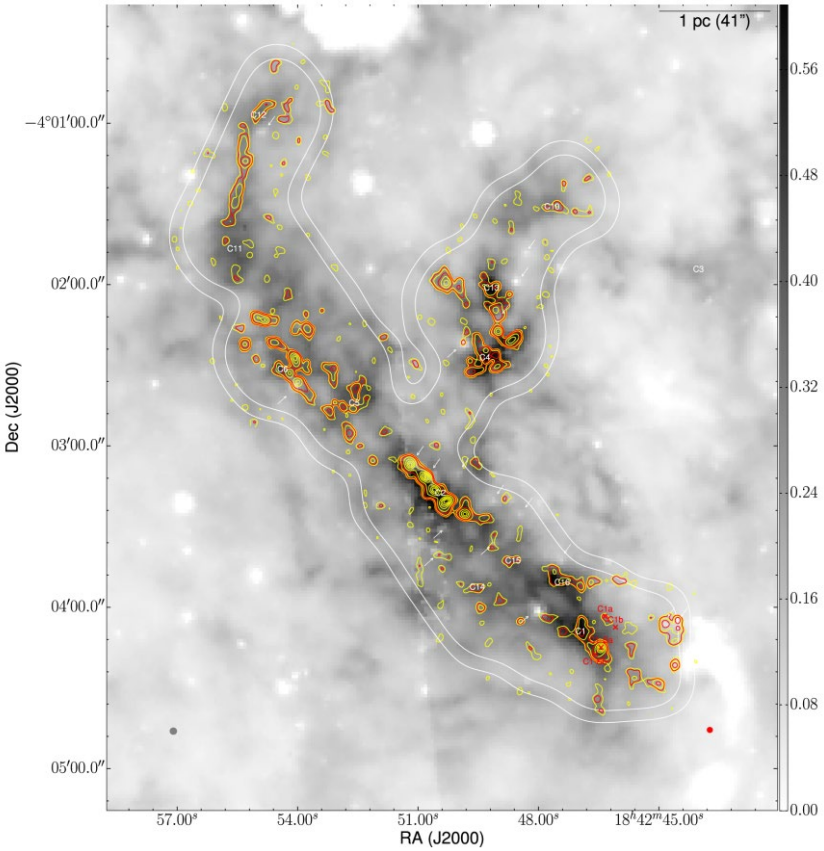



***Figure 3.2.*** *Grayscale: MIR extinction derived mass surface density map from Butler, Tan & Kainulainen (2014) (scale in g/cm$^2$). The angular resolution of the map is shown as the gray filled circle at the lower left. "C1, C2, C3..." label extinction peaks. The white arrows point to possible embedded protostars that show as local enhancements in the Spitzer 8 micron image, which produce local "holes" in the extinction map. Contours: ALMA 1.3 mm continuum mosaic. The contours range from S/N = 2, 3, 5, 10, 20, 40, 60, ... with the rms noise at map center of ~0.2 mJy/beam. The two red contours highlight S/N = 3 and 10. The synthesized beam is shown as the red filled ellipse at the lower right. The two white enclosing contours show primary-beam responses of 0.3 (outer) and 0.5 (inner).*

## 3.2 APEX

*[Module 3]*

***Circumstellar environment of the M-type AGB star R Doradus: APEX spectral scan at 159.9-368.5 GHz***

E. De Beck and H. Olofsson

A&A 615, A8 (2018)

*Summary:* This observationally comprehensive APEX study of the asymptotic giant branch (AGB) star R Doradus covers almost the entire wavelength region 0.8-1.9 mm, see Fig. 3.3. Hundreds of molecular spectral lines were detected in the star's gaseous envelope despite its rather low mass-loss rate. Most of these lines are of thermal origin but a few also exhibit maser characteristics. This large set of molecular line data will not only be useful when delineating the chemistry of circumstellar envelopes and the molecular formation processes but it will also be of aid in the characterisation of the physical conditions throughout the stellar atmosphere. Most spectral lines, of the 320 lines detected, toward the star were identified with a certain molecular species, but in 16 cases the observed spectral features remain unidentified.

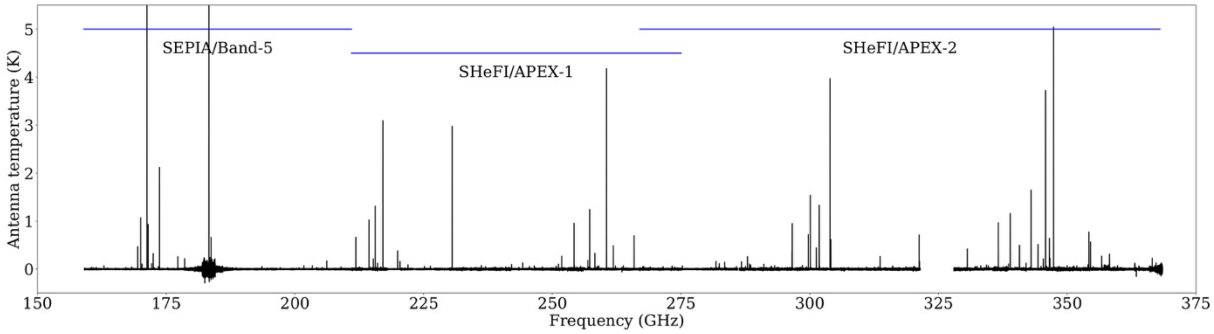



***Figure 3.3.*** *The entire observed spectrum of R Doradus covering most of the band 160-368GHz utilising 3 different receivers (SEPIA B5, APEX-1 and APEX-2). Only the strongest spectral lines are visible as spikes with this scaling. The noisy part around 183 Hz is due to the strong atmospheric attenuation near the telluric water line (but the stellar water maser line is anyway readily detected).*

***Cold gas in a complete sample of group-dominant early-type galaxies***

E. O'Sullivan, F. Combes, P. Salomé, L. P. David, A. Babul, J. M. Vrtilek, J. Lim, V. Olivares, S. Raychaudhury, and G. Schellenberger

A&A 618, A126 (2018)

*Summary:* Together with the IRAM 30m telescope, APEX was used to observe several group-dominant early-type galaxies. From the CO detections, it is clear that this kind of galaxies have low star-formation rates but rapid replenishment of their gas reservoirs. Moreover, a much higher fraction of the group-dominated galaxies does have active galactic nuclei (AGN) as compared to elliptical galaxies in general.

***Measuring the molecular abundances in comet C/2014 Q2 (Lovejoy) using the APEX telescope***

M. de Val-Borro, S. N. Milam, M. A. Cordiner, S. B. Charnley, I. M. Coulson, A. J. Remijan and G. L. Villanueva

MNRAS 474, 1099 (2018)

*Summary:* The APEX telescope was used to study the long-period comet C/2014 Q2 (Lovejoy) in early 2015 when it was at a distance of about 0.5 AU from Earth. Four different molecules were detected in the cometary coma: HCN, $CH_3OH$, $H_2CO$ and CO. The methanol molecule can be used to determine the temperature of the coma gas. At the time of the observations the

temperature was determined to about 50 K. The production of CO, HCN and $H_2CO$ molecules, relative to that of water, was lower than normally observed toward comets. The chemical composition of cometary comae is thought to reflect the conditions prevailing when our solar system was formed.

### 3.3 Astronomical VLBI

*[Module 4]*

***A dust-enshrouded tidal disruption event with a resolved radio jet in a galaxy merger***

Mattila, S.; Pérez-Torres, M.; Efstathiou, A.; Mimica, P.; Fraser, M.; Kankare, E.; Alberdi, A.; Aloy, M. Á.; Heikkilä, T.; Jonker, P. G.; Lundqvist, P.; Martí-Vidal, I.; Meikle, W. P. S.; Romero-Cañizales, C.; Smartt, S. J.; Tsygankov, S.; Varenius, E.; Alonso-Herrero, A.; Bondi, M.; Fransson, C.; Herrero-Illana, R.; Kangas, T.; Kotak, R.; Ramírez-Olivencia, N.; Väisänen, P.; Beswick, R. J.; Clements, D. L.; Greimel, R.; Harmanen, J.; Kotilainen, J.; Nandra, K.; Reynolds, T.; Ryder, S.; Walton, N. A.; Wiik, K.; Östlin, G.

Science 361, 482 (2018)

*Summary:* Tidal disruption events (TDEs) are transient flares produced when a star is ripped apart by the gravitational field of a supermassive black hole (SMBH). In a TDE, roughly half of the star's mass is ejected, whereas the other half is accreted onto the SMBH, generating a bright flare that is normally detected at X-ray, ultraviolet (UV), and optical wavelengths. TDEs are also expected to produce radio transients, lasting from months to years and including the formation of a relativistic jet, if a fraction of the accretion power is channeled into a relativistic outflow.

An international team of astronomers (including researches from Stockholm and Chalmers) have, for the first time, directly imaged the formation and expansion of a fast-moving jet of material ejected when the powerful gravity of the SMBH in the nucleus of Arp 299-B ($D$ = 45 Mpc) ripped apart a star that wandered too close to the cosmic monster. It is one of the two merging galaxies (Arp 299-A and Arp 299-B) forming the Arp 299 system, which hosts prolific supernova factories in its nuclear regions.

The team tracked the event with radio and infrared telescopes, including the EVN, for over a decade. The patient, continued observations with the EVN and other radio telescopes around the world, eventually showed the source of radio emission expanding in one direction, just as expected for a jet (Fig. 3.4). The measured expansion indicated that the material in the jet moved at an average of about one-fourth the speed of light. The crucial piece of information solving the puzzle of this event was provided by VLBI observations, as the inferred angle of the jet to the line-of-sight was in clear disagreement with expectations from a "normal" AGN jet, while in the case of a TDE this angle can have any value.

The gravitational field of the SMBH in Arp 299-B, with a mass 20 million times that of the Sun, shredded a star with a mass more than twice that of the Sun. This resulted in a TDE that was not seen in the optical or X-rays because of the very dense medium surrounding the SMBH, but was detected in the near-infrared and radio. The soft X-ray photons produced by the event were efficiently reprocessed into UV and optical photons by the dense gas, and further to infrared wavelengths by dust in the nuclear environment. Efficient reprocessing of the energy might thus resolve the outstanding problem of observed luminosities of optically detected TDEs being generally lower than predicted.

The case of Arp 299-B AT1 suggests that recently formed massive stars are being accreted onto the SMBH in such environments, resulting in TDEs injecting large amounts of energy into their surroundings. However, events similar to Arp 299-B AT1 would have remained hidden within dusty and dense environments, and would thus not be detectable by optical, UV or soft X-ray observations. Such TDEs from relatively massive, newly formed stars

might provide a large radiative feedback, especially at higher redshifts where galaxy mergers and luminous infrared galaxies like Arp 299 are more common.

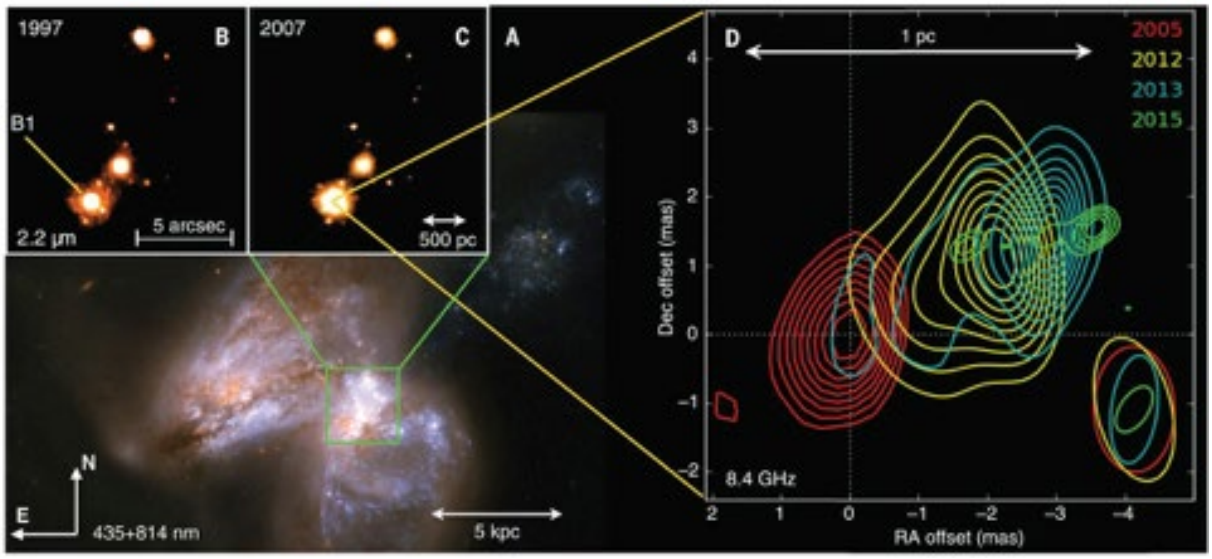



***Figure 3.4.*** *The tidal disruption event Arp 299-B AT1 and its expanding radio jet. (A) A color-composite optical image from the HST, with high-resolution, near-IR 2.2 micron images [insets (B) and (C)] showing the brightening of the B1 nucleus. (D) Radio evolution of Arp 299-B AT1 as imaged with VLBI at 8.4 GHz [7× 7 milli-arcsec (mas) region with the 8.4-GHz peak position in 2005, indicated by the dotted lines]. The VLBI images are aligned with an astrometric precision better than 50 microarcsec. The initially unresolved radio source develops into a resolved jet structure a few years after the explosion, with the centre of the radio emission moving westward with time at an average intrinsic speed of 0.22 times the speed of light. The radio beam size for each epoch is indicated in the lower-right corner.*

***SHARP – V. Modelling gravitationally lensed radio arcs imaged with global VLBI observations***

Spingola, C.; McKean, J. P.; Auger, M. W.; Fassnacht, C. D.; Koopmans, L. V. E.; Lagattuta, D. J.; Vegetti, S.

Monthly Notices of the Royal Astronomical Society 478, 4816 (2018)

*Summary:* The Strong lensing at High Angular Resolution Program (SHARP) led by McKean (Astron) has obtained a deep global VLBI observation of the gravitational lens MG J0751+2716 at 1.65 GHz. The 18.5 hours observation comprised 24 antennas from the EVN and the VLBA, including the 25 m telescope in Onsala. The data were recorded at 512 Mbps and correlated at JIVE to produce eight spectral windows (IFs) with 8 MHz bandwidth and 32 channels each, through both circular polarisations. MG J0751+2716 is one of the few quadruply imaged radio-loud gravitationally lensed quasars that show extended arcs on VLBI-scales. The global VLBI L-band deep imaging detects all of the extended arcs at high significance, showing the complex surface brightness structure of the background source in unprecedented detail (Fig. 3.5). The total flux density of the target is 350 mJy and the off-source rms is 41 μJy/beam. Never before have such extended (200-600 mas) gravitational arcs been detected at an angular resolution of a few microarcseconds. The excellent uv-coverage and surface brightness sensitivity provided by the global VLBI array have been fundamental for a precise study of the structure of the extended arcs on mas-scales from MG J0751+2716.

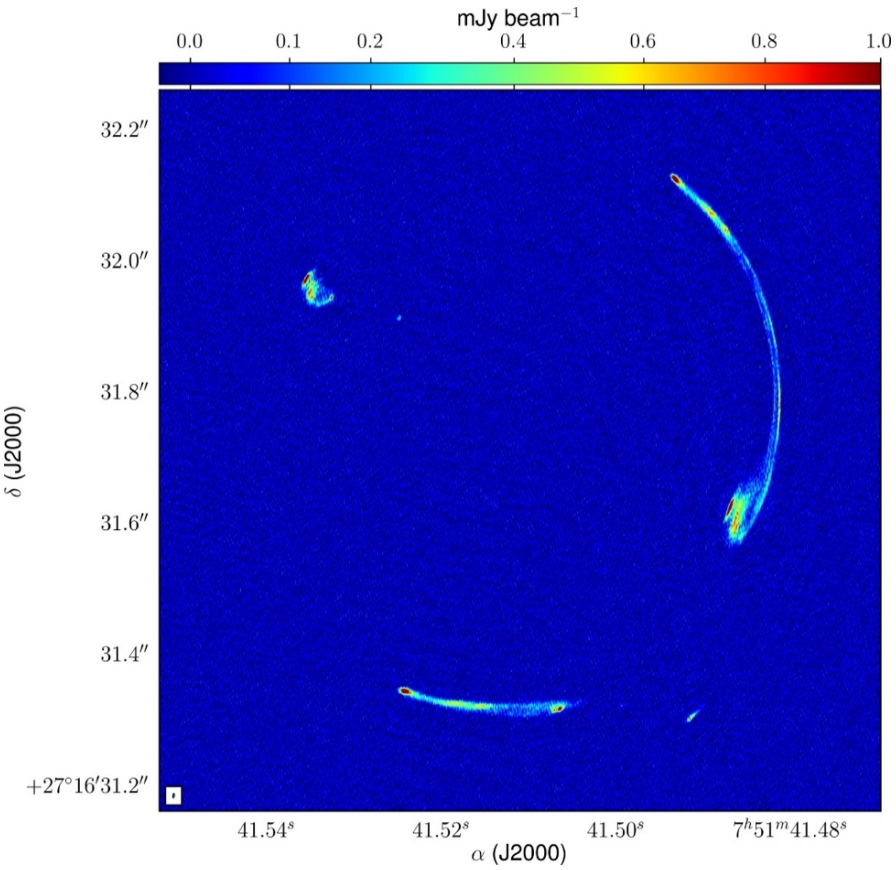



***Figure 3.5.*** *Global VLBI imaging of MG J0751+2716 at 1.65 GHz (Spingola et al. (2018)). The off-source rms is 41 μJy/beam and the peak surface brightness is 2.9 mJy/beam. The restored beam is 5.5x1.8 mas$^2$, and is shown within the white box in the bottom left hand corner.*

## 3.4 LOFAR

*[Module 5]*

***Reliable detection and characterization of low-frequency polarized sources in the LOFAR M51 field***

A. Neld, C. Horellou, D. D. Mulcahy, R. Beck, S. Bourke, T. D. Carozzi, K. T. Chyży, J. E. Conway, J. S. Farnes, A. Fletcher, M. Haverkorn, G. Heald, A. Horneffer, B. Nikiel-Wroczyński, R. Paladino, S. S. Sridhar and C. L. Van Eck

Astronomy & Astrophysics 617, A136 (2018)

*Summary:* This work lead by OSO researchers developed a rigorous algorithm for detecting polarized sources at low frequencies using the LOFAR telescope. This work is important towards the goal of developing a dense grid of polarized sources. These will ultimately be used o probe the interstellar media for magnetized plasma and help us to understand the role of magnetic fields in astronomy using the so-called Faraday rotation effect. The authors used polarimetric LOFAR images of the M51 field and extracted sources. Then, by using statistical hypothesis testing, they determined the probability values (p-values) of the null-hypothesis that a source was unpolarized. This allowed the authors to detect the polarized sources that could be used of Faraday rotation synthesis.

***Polarized point sources in the LOFAR Two-meter Sky Survey: A preliminary catalog***
Van Eck, C. L.; Haverkorn, M.; Alves, M. I. R.; Beck, R.; Best, P.; Carretti, E.; Chyży, K. T.; Farnes, J. S.; Ferrière, K.; Hardcastle, M. J.; Heald, G.; Horellou, C.; Iacobelli, M.; Jelić, V.; Mulcahy, D. D.; O'Sullivan, S. P.; Polderman, I. M.; Reich, W.; Riseley, C. J.; Röttgering, H.; Schnitzeler, D. H. F. M.; Shimwell, T. W.; Vacca, V.; Vink, J.; and White, G. J.
Astronomy & Astrophysics 613, A58 (2018)
*Summary:* The authors report on the preliminary development of a data reduction pipeline to carry out polarization processing and Faraday tomography for data from the LOFAR Two-meter Sky Survey (LOTSS) and present the results of this pipeline from the LOTSS preliminary data release region. They have produced a catalog of 92 polarized radio sources at 150 MHz at 4.′3 resolution and 1 mJy rms sensitivity, which is the largest catalogue of polarized sources so far produced at such low frequencies.

## 3.5 Onsala 20 m telescope single dish

***Detection of methanol lines in comet 46P/Wirtanen***
M.S. Lerner, A.O.H. Olofsson, P. Bergman, E.S. Wirström, in prep.
*Summary:* In December 2018, comet 46P/Wirtanen (the original target for the Rosetta mission) passed unusually close to the Earth. Within the framework of the Onsala 20 m proposal O2018a-03, starting 2018-12-07 this comet was observed for most of the time it was visible in our northern sky until the end of the year, with the exception of 7 days when the telescope was dedicated to geodetic S- and X-band observations. Most of the time was spent observing the HCN (hydrogen cyanide) triplet at 88.6 GHz, which made it possible to monitor the activity of the comet. When the weather was good, the observations were switched to several methanol lines near 95 GHz, of which seven were detected after ca 60 hours of total observation time, see Fig. 3.6. While HCN can be used to estimate the total gas production rate, methanol will give additional information on the gas temperature.

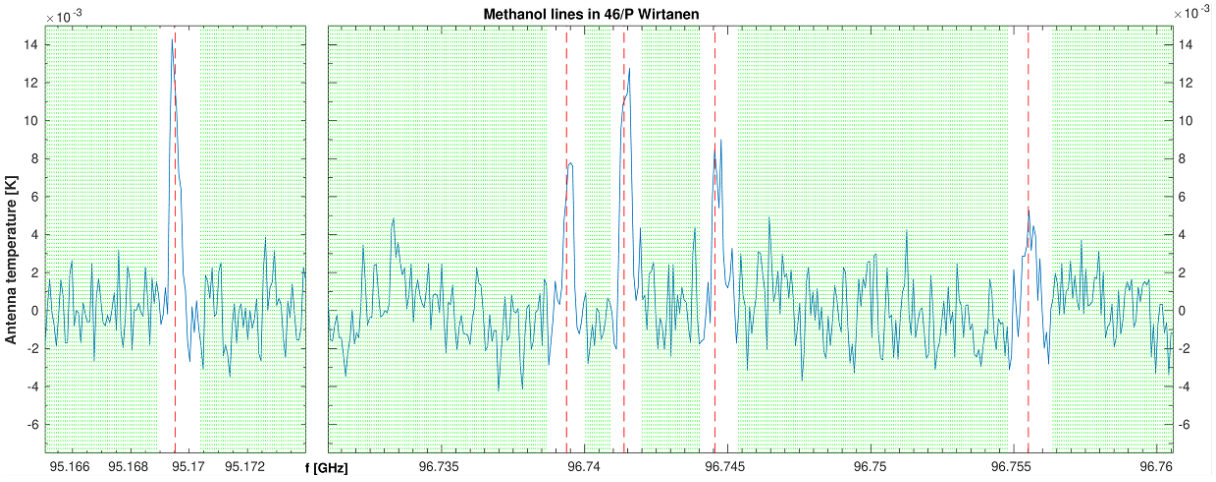



***Figure 3.6.*** *Onsala 20 m telescope observations of methanol in comet 46T/Wirtanen.*

***SO survey of massive cores***
I. Zinchenko & C. Henkel
IAUS 332, 274 (2018)
*Summary:* At the "Astrochemistry VII: Through the Cosmos from Galaxies to Planets" IAU symposium, Zinchenko & Henkel presented results from a joint Onsala/Effelsberg observational campaign. With the Onsala 20 m telescope, they observed 35 massive star forming regions in two sulphur monoxide (SO) transitions near 100 GHz. With the Effelsberg telescope,

they observed the SO ground state transition at 30 GHz where the beam size is similar to that of the 20 m telescope at 100 GHz, which is of great advantage for this kind of study. They found SO abundances in the range $(0.5-4)\times10^{-9}$ in gas with number densities in excess of $10^6$ $cm^{-3}$ using RADEX modelling. The faint pure fine structure transition $J_N = 4_5 - 4_4$ at 100.0296 GHz was detected in three of the sources (W3, W51, ON2). This result may help in resolving some discrepancies between models and observations in our understanding of the important sulphur chemistry.

### 3.6 Geosciences

*[Module 6]*

***VLBI observations to the APOD satellite.***
Sun, J.; Tang, G.; Shu, F.; Li, X.; Liu, S.; Cao, J.; Hellerschmied, A.; Böhm, J.; McCallum, L.; McCallum, J.; Lovell, J.; Haas., R.; Neidhardt, A.; Lu, W.; Han, S.; Ren, T.; Chen, L.; Wang, M.; Ping, J.
Advances in Space Research 3, 823 (2018)
*Summary:* This article presents first results from the observation of low earth orbit co-location satellite with geodetic VLBI. Such kind of satellites are a very promising approach for the improvement of the terrestrial reference frame since they have the capability to act as co-location points in space. The Chinese prototype co-location satellite APOD was observed with regional VLBI networks in Europe and Australia and first results of the data analysis presented.

***Source Structure and Measurement Noise Are as Important as All Other Residual Sources in Geodetic VLBI Combined.***
Anderson, J.; Xu, M.H.
J. Geophys. Res. – Solid Earth 123, 10162 (2018)
*Summary:* This article shows that source structure is a major contributor to errors in geodetic VLBI, and source structure must be taken into account in the entire VLBI operational chain, from scheduling to analysis, in order to mitigate its effects on astrometric and geodetic measurements. This is in particular important for the upcoming next generation VLBI system.

***Link between the VLBI and Gaia Reference Frames.***
Liu, J.C.; Zhu, Z.; Liu, N.
Astronomical Journal 156, A13 (2018)
*Summary*: The link between the International Celestial Reference Frame at radio wavelength and the forthcoming Gaia optical reference frame is a mandatory task after the completion of the Gaia mission. It is shown that the VLBI reference frame can be linked to Gaia based on thousands of common quasars with an accuracy of 10 μas for each axis.

### 3.7 Device physics and Terahertz technology

*[Module 8]*

***Noise and IF gain bandwidth of a balanced waveguide NbN/GaN hot electron bolometer mixer operating at 1.3 THz***
S. Krause, D. Meledin, V. Desmaris, A. Pavolotsky, H. Rashid, V. Belitsky
IEEE Trans. Terahertz Sci. Technol., Vol. 8, Issue. 3 (2018)
*Summary:* Hot Electron Bolometer (HEB) mixers are devices employing the phenomenon of heating electron gas in superconducting micro-bridge for down conversion of electromagnetic radiation. Since their introduction in late 1990s, HEB mixers have been inherently limited in the intermediate frequency (IF) band by the escape time of the phonons.

The Group for Advance Receiver Development (GARD) has worked for a long time on solving the problem of the limited IF band of HEBs. Understanding the physical origin of the IF bandwidth limitations of HEBs, and combining with its unique competence in terms of nano-device fabrication and superconducting thin-film deposition, GARD has demonstrated that with the use of the GaN buffer layer one could drastically improve the quality of the NbN ultra-thin films which constitute the basis of the HEB mixers. In fact, the use of such buffer layer and the NbN deposition process developed at GARD results in nearly epitaxial film structure that illustrated in Fig. 3.7 below.

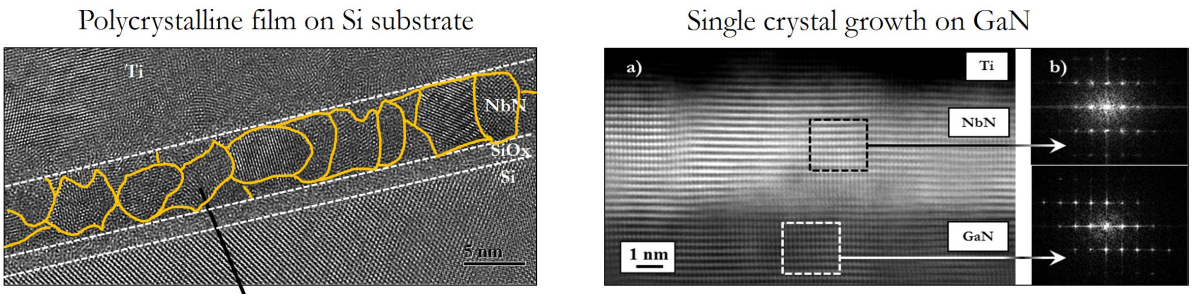



***Figure 3.7.*** *Comparison of the NbN film structure grown on Si and GaN substrates. The NbN film grown on GaN substrate demonstrates regular atomic structure that is typical for single-crystal epitaxial films.*

Based on the NbN films described above, GARD designed and produced waveguide balanced HEB mixer operating at around 1.3 Terahertz RF frequency. The results of the measurements for this mixer presented in Fig. 3.8 for the IF frequency in comparison with other world best mixers' performance clearly demonstrates that the HEB mixers produced at GARD supersedes today's state-of-the-art HEB mixers used at the best observatories.

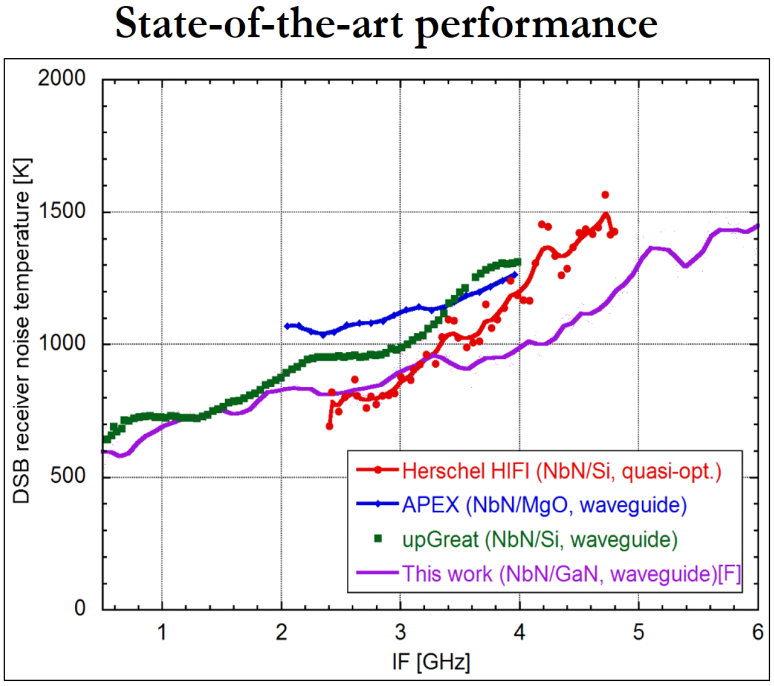



***Figure 3.8.*** *GARD produced HEB mixer IF performance (purple curve, Tx noise temperature vs IF frequency, the lower is the better) in comparison with other world-best HEB receivers.*

# 4 Instrument upgrades and technical R&D

## 4.1 ALMA

*[Modules 2 & 8]*

During 2018, GARD continued to work on the ALMA Band 5 Full Production project. A few remaining ALMA Band 5 receiver cartridges wete finished and delivered to the ALMA Observatory. Most of the effort in this completing part of the Project was focused on producing spare Band 5 2SB mixer assemblies. Totally, GARD during 2018 produced 20 pieces of the ALMA Band 5 2SB mixers. There were a couple of guaranty cases which were all completed by 3 December 2018, and the ALMA Band 5 Project was successfully closed. Figure 4.1 shows the ALMA Band 5 2SB mixer assembly.

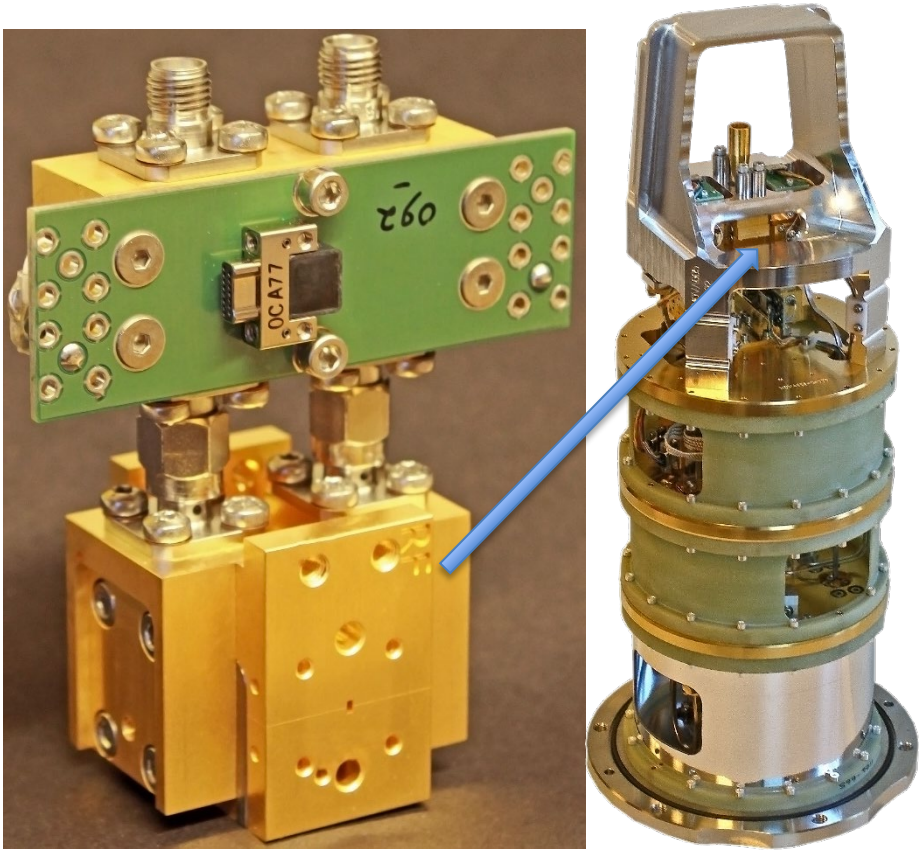


***Figure 4.1.*** *Left: ALMA Band 5 2SB mixer assembly. Right: ALMA Band 5 Cold Cartridge Assembly.*

The ALMA observatory has released the ALMA development roadmap, describing the strategic vision and priorities for the development of new capabilities for ALMA out to 2030. The roadmap sets the framework for future R&D activities related to ALMA. The current development priorities are to broaden the receiver IF bandwidth by at least a factor two and to upgrade the associated electronics and correlator. The full development roadmap can be found on the ALMA Observatory homepage at:
https://www.almaobservatory.org/en/publications/the-alma-development-roadmap/

Onsala Space Observatory has continued its involvement in the RadioNet JRA RINGS (see Sects. 4.4 and 9), e.g., OSO has worked on full polarisation and beam modelling for polarisation calibration with ALMA (and LOFAR).

## 4.2 APEX

*[Modules 3 and 8]*

In the first few months of 2018, a major upgrade of the APEX telescope in Chile took place as planned. The wobbler, secondary mirror (subreflector) and main dish panels were replaced in order to improve the surface aiming at a goal of having an overall surface accuracy of 10 microns (over the 12 m dish). The wobbler and subreflector upgrades were very successful and both components have been in use since normal observation commenced in April 2018. Also, the major task of replacing panels went technically well although some problems related to the panel adjustment devices were discovered and will be remedied in early 2019. After the improvements made during 2018 the surface could be set to an accuracy a few microns short of the final goal, with every prospect of reaching the goal during 2019 after the final adjustments are made.

OSOs receiver group at Chalmers, GARD, performed two missions to APEX, both connected to SEPIA (Swedish ESO PI receiver for APEX) that was initially installed at the APEX telescope in early 2015. After the major upgrade of the telescope, the SEPIA receivers were supposed to be re-installed in the Nasmyth Cabin A at the beginning of 2018. However, because of an accident in handling the receiver during its installation it was damaged and had to be returned to Chalmers to undergo major repairs. The refurbishing and repair of the SEPIA cryostat took about 3 months; the opportunity was taken during this period to make further improvements to the cryostat. The receivers were successfully installed in the telescope in August 2018. In parallel with this work, efforts continued with the re-positioning work of the cryostat since the final goal (from 2019 onward) is that should occupy the facility receiver position, not in the visitor receiver position. To achieve this goal requires a complete redesign of the SEPIA tertiary optics which was started during 2018. The software for controlling the SEPIA receivers was also upgraded during 2018 so that now all the SEPIA receiver channels, SEPIA180 (Band 5), SEPIA660 (Band 9), and the future SEPIA345 (Band 7), are being controlled by the same routines.

In August 2018, the upgraded SEPIA660 receiver (built by the Dutch NOVA group) was installed successfully at APEX within the SEPIA instrument. This receiver operates mainly in the 600 GHz atmospheric window. The upgrade consisted of two large improvements. Firstly, the old double side-band operation was changed into full 2-sideband operation meaning that each side band is now recorded individually and thus increasing the simultaneous frequency coverage by a factor of two. This change will substantially improve projects related to spectral line surveys for which it is advantageous to cover a large frequency range. It will also aid greatly in the identification of spectral lines in complex line-rich sources since now lines coming from different side bands will not be blended together and cause confusion. It should be noted that the suppression of signal leakage into the unwanted side band was measured to be very good. Secondly, the frequency range has been increased taking advantage of the high atmospheric transmission at the APEX site. The useable range is now 581−727 GHz which is an increase in the available frequency range by more than 10%.

SEPIA660 was technically and scientifically commissioned in August and October 2018 and accepted by the APEX board in early November to be used for scientific observations. Science verification observations were made in October 2018 using projects from all APEX partners. This data became public in November and can be retrieved from the ESO archive. Two of the projects were Swedish and for one of the science verification projects, SEPIA660 results are already included in a very recent publication (Olofsson et al. 2019, A&A 623, 153).

## 4.3 Astronomical VLBI

*[Module 4]*

The disk capacity of the OSO FlexBuff at JIVE has been increased in 2018. The 80 Hz continuous calibration system has been installed at S and X bands on the 20 m telescope and been used since EVN Session 2, 2018. Since 2018, VLBI operation uses the new antenna control software called Bifrost for both the 20 m and the 25 m telescopes.

OSO is involved in the VLBI related H2020 project JUMPING JIVE (see Sect. 9). During 2018, OSO has continued its involvement in work package 7, (WP7, 'The VLBI future'). The main deliverable of this WP will be a document, in the form of a White Paper, that will address and explore several relevant points in setting the future priorities of VLBI science capabilities.

The BRoad-bAND (BRAND) RadioNet project (see Sect. 9) is developing a revolutionary decade frequency range (1.5–15.5 GHz) receiver for VLBI. Onsala Space Observatory is leading the feed design where the first prototype is optimised for the prime-focus geometry of the Effelsberg 100 m telescope. The feed has been manufactured and is currently being tested. In parallel, high performance Low Noise Amplifiers (LNAs) have been designed and manufactured by the Yebes observatory (IGN), Spain. The LNAs will be integrated together with the feed in the receiver cryostat in 2019. The BRAND EVN partners include Germany (MPIfR), Italy (INAF), Sweden (OSO), Spain (IGN), The Netherlands (ASTRON), and Latvia (VIRAC).

Algorithm and software development relevant to VLBI forms part of the Radio Interferometry Next Generation Software (RINGS) RadioNet project; this project is described in more detail in Sects. 4.4 and 9.

## 4.4 LOFAR

*[Module 5]*

During the last year, Onsala Space Observatory has been involved in the LOFAR For Space-Weather (LOFAR4SW) project. LOFAR4SW is an EU funded Horizon 2020 Work Programme. It consists of a design study that will look at how the radio telescope LOFAR, which has a Swedish station, can be upgraded to become a space-weather observatory that runs continuously and independently of LOFAR's radio astronomy operations. In particular OSO has been involved in studying the software requirements of LOFAR4SW. The goal is to define requirements on software in terms of control, monitoring, pipeline processing and archiving. We are also investigating how LOFAR4SW can be become an event driven observatory, responding to solar events triggered by both external and internal real-time data sources. The LOFAR4SW effort will build on the LOFAR2.0 project that consists of upgrading LOFAR stations to allow for a second independent beam so that multiple, simultaneous science targets become possible.

Onsala Space Observatory has continued its involvement in the RadioNet JRA RINGS (see Sect. 9). The main objective for RINGS is to deliver advanced calibration algorithms for the next generation of radio astronomy facilities, characterized by high sensitivity, high bandwidth and long baselines. During 2018, OSO has continued is work in WP7.2 which involves full polarisation and beam modelling for polarisation calibration with ALMA and LOFAR, including polarisation conversion from linear to circular polarisation products. In WP7.5, OSO has focused with RINGS on developing automated self-calibration routines.

## 4.5 The Onsala 20 m telescope

*[Modules 4,6]*

In order to repair water damage and general wear and tear, during December 2017/January 2018 the 20m telescope subreflector system was taken down from the telescope and rebuilt. All motors and gauges were replaced, all mechanical parts were checked and replaced were needed. The control system and motor drivers were replaced and placed in an RF tight enclosure close to the motors and gauges at the subreflector mounting frame (replacing the old system where cables ran along the subreflector legs connecting the motors and gauges with the old control system). Communication with the new control system is now done via fiber to reduce RFI.

The new subreflector system was sky commissioned in February and it was proven that we can now make measurements of the antenna/subreflector behaviour for all X/Y/Z-axes at all elevations thanks to the extended operating ranges. We could also measure the pointing response with respect to tilt changes (through differential Z-motion) and start evaluating if the telescope efficiency can be improved by introducing tilt-vs-elevation models. The subreflector motion is now significantly faster which has reduced the overhead time when doing focus measurements, or, when switching between sources at high and low elevation. Other improvements include: more robust control code for the Path Length Modulator (PLM) which moves the 3/4-mm receiver back-and-forth to reduce standing waves, and new options for how switched observations are carried out to improve symmetry. The new control system, Bifrost, is now employed when running all types of interferometric observations and it was used in three pilot single-dish science projects, one of which was a spectral survey that could benefit from the automatic re-tunings and book-keeping of observation times for each frequency and source. Since autumn 2018, Bifrost is also used for all types of maintenance observations.

In August 2018 a pyranometer (Kipp & Zonen SMP6-V) was installed to measure the solar irradiance. The solar irradiance is one factor affecting the shape of our 20 m parabolic dish during daytime, with these effects being most evident at the highest frequencies. We plan to incorporate data from the pyranometer into a model for focus predictions of our subreflector when using the 3 and 4 mm receivers.

## 4.6 Geoscience

*[Module 6]*

The tide gauge station has been an official monitoring site in the national sea level network since the summer of 2015. The goal of having an accuracy in terms of long-term stability of just a couple of millimetres requires the use the very best sensors. During the time of operation, the root-mean-square (RMS) difference between the laser sensor and the prime sensor (the Campbell CS476, a 26 GHz radar sensor) has been of the order of 3–4 mm. There are reasons to believe that the major systematic error of the radar sensor is signal mutipath in the well. In order to assess this assumption, a high frequency radar (VEGAPULS64 operating in the 76–80 GHz frequency range) was installed after the summer of 2018. The main difference between the two radar sensors is the beam angles. The VEGAPULS64 has an opening angle (full-width half maximum) of 3° instead of the 8° of the CS476 sensor. Both sensors are mounted in the concrete well. The electronic laboratory staff has not been able to detect any radiation transmitted through the concrete wall, i.e., the radars do not cause any RFI.

The new pyranometer which measures solar irradiance (see Sect. 4.5), primarily for correcting 20m telescope pointing, is also important addition to other instruments at Onsala observing the atmosphere.

## 4.7 Development of new millimetre/sub-millimetre devices

*[Module 8]*

The Group for Advanced Receiver Development, GARD, runs a project to develop processing for fabrication on a **new type of superconducting tunnel junctions**, superconductor-insulator-superconductor (SIS), with AlN tunnel insulation barrier. SIS junctions are primarily used in SIS mixers for frequencies 86−1200 GHz and are the dominating technology for radio-astronomy instrumentation at these frequencies. Compared to currently used SIS junctions with $Al_xO_y$ tunnel barrier, AlN barrier-based junctions promise lower specific capacitance and a possibility to realize the junctions with about 10 times higher current density. The two mentioned advantages give potential to make even more broadband RF/IF-wise mixers that should satisfy demand on new generation instruments for, e.g., the ALMA Observatory. Currently, GARD has established the process of fabrication of the AlN barrier-based SIS junctions in Chalmers Clean Room Facility using dedicated equipment. Figure 4.2 demonstrates the current voltage characteristic of such junctions showing excellent device quality with Rj/Rn ratio above 20 for a wide range of current densities. The measurements were performed at 4 K physical temperature.

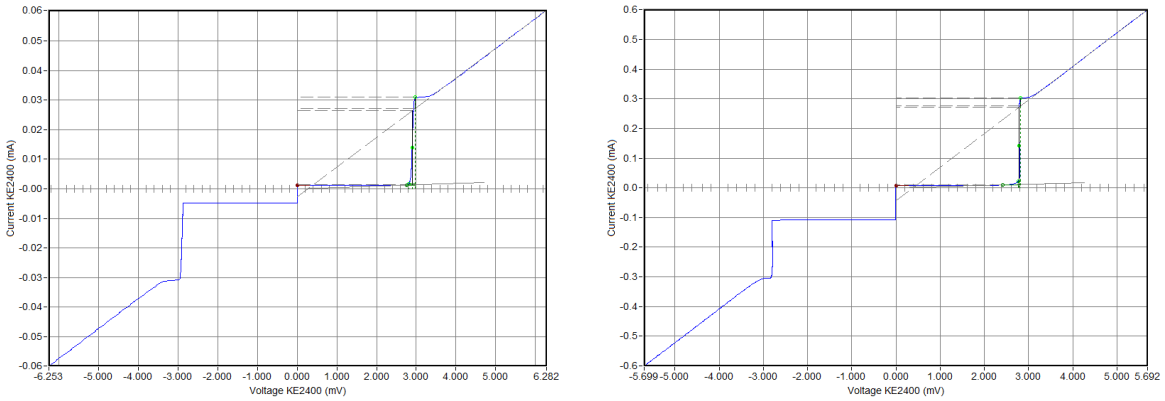



***Figure 4.2.*** *Typical current-voltage-curves (IVCs) of Nb/AlN/Nb junctions.*
*Left: RnA ~ 130 Ohm x μm², 1.5 μm², Rj/Rn ~ 30. Right: RnA ~ 15 Ohm x μm², 1.5 μm², Rj/Rn ~ 25.*

The project includes establishing the processing with stable and predictable yield of the junctions and characterization of the Nb/AlN/Nb SIS junction specific capacitance, and should be completed during 2019. This project is co-funded by ESO through the ALMA Upgrade program and H2020 RadioNet JRA AETHRA.

Another big project during 2018 was developing, designing and implementation of the **SEPIA Band 7 receiver cartridge** covering the frequency band 211−376 GHz. The design of the SEPIA receiver was driven by the idea of using ALMA receiver cartridges on the APEX telescope. However, old ALMA receiver cartridges are specified to have 4−8 GHz IF band, while for the new generation of APEX receivers this is doubled to 4−12 GHz IF. GARD is designing the entirely new receiver cartridge which follows the ALMA guideline but uses all original optics, feed, OMT and mixers with their IF system. This is an extensive project and we here present only some pictures and results, in Figs. 4.3 and 4.4.

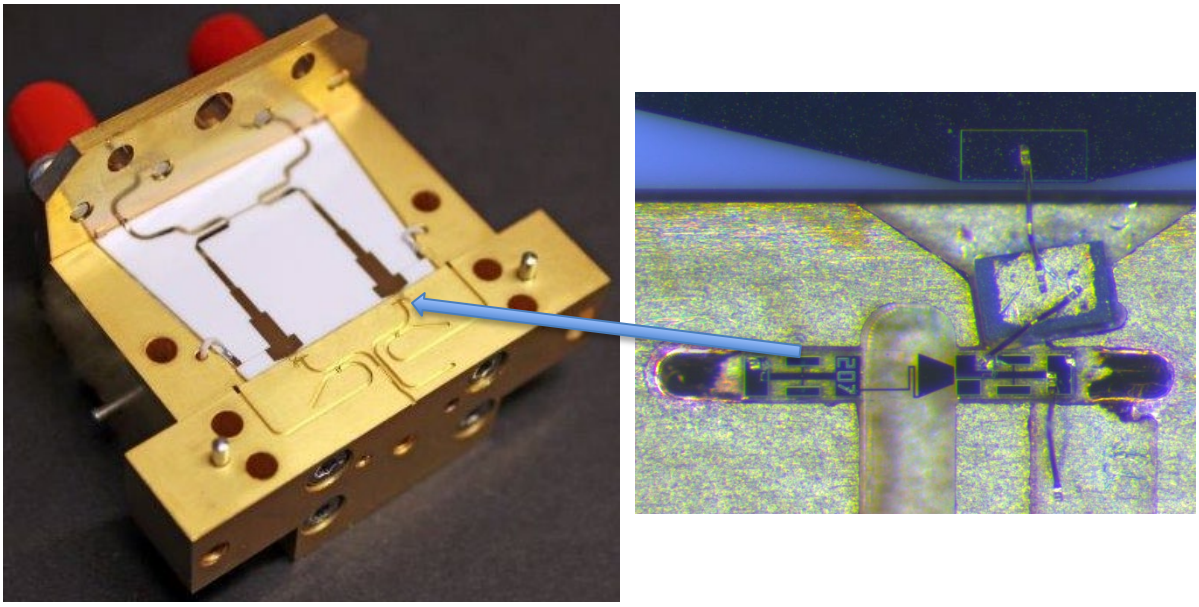
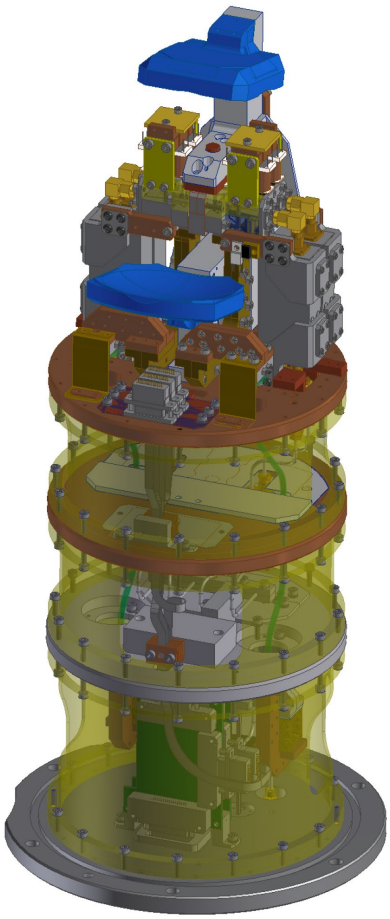


***Figure 4.3.*** *Left: The GARD designed SEPIA Band 7 2SB mixer. Right: detailed view of the mixer chip integrated into the mixer block. The waveguide dimensions are 400 x 800 µm.*

***Figure 4.4.*** *CAD drawing of the SEPIA Band 7 receiver cartridge. The cartridge design is using the body and some construction elements of ALMA Band 5 pre-production cartridge. This is done to speed up development and gain some cost advantage. This however leads also to some compromises in the layout of components and the entire design of the receiver. During 2018, GARD produced most of the components of the new SEPIA Band 7 receiver, including optics (blue parts in the CAD drawing), OMT and some other parts.*



**Other activities and projects.** As part of the H2020 RadioNet JRA AETHRA project, GARD works on the design of ultra-wideband SIS mixers. The purpose of the project is to probe the boundaries of the existing technologies and put them to new limits. GARD is involved in the designing and experimental testing of balanced cryogenic HEMT amplifiers; this work is

performed in collaboration with Spanish group at Yebes with already achieved some interesting and promising results. GARD continues to work with HEB technology development, and during 2018 we demonstrated outstanding quality of the ultra-thin NbN superconducting films and even made HEB mixer prototype at 1.3 THz with record-wide IF bandwidth (for more details, see Sect. 3.7). Finally, GARD is working on upgrading the computer control system for the dedicated sputter machine that is the main work-hours for fabrication SIS junctions. The sputter is getting into 20 years of age, and while its vacuum parts and associated devices are kept in perfect shape, the control system based on an out-fashioned computer (Windows 95) needs replacement. This project has strong technical aspect but is yet very complex and requires deep insight into processing details, vacuum technique, electronics and software. We expect a successful completion of the project in the first half of 2019.

# 5 SKA design activities

*[Module 9]*

During 2018, OSO continued its technical involvement in the Square Kilometre Array (SKA), an international project aiming to build a new astronomical facility serving the radio waveband at metre and centimetre wavelengths. SKA will be co-hosted by South Africa and Australia. The main bulk of the SKA will be built in two main phases, between 2019 and the late 2020s, the first phase will involve testing the full system in a "proof of concept" manner.

OSO is involved in three work packages of the design phase of the SKA project. OSO is designing the feed and LNA package of Band 1 in the Dish Consortium. OSO is the consortium leader for the Wide Band Single Pixel Feed (WSPF) Advanced Instrumentation Program (AIP) for SKA. Finally, OSO participates in the Phase Array Feed advanced instrumentation program.

## 5.1 Band 1 in SKA-DC

Onsala Space Observatory is involved in the design phase of the SKA project with the responsibility to design the feed package for Band 1 of SKA-mid (see Fig. 5.1). This receiver's frequency coverage of 350–1050 MHz will open the possibility to map highly redshifted HI with very high spatial resolution.

***Figure 5.1.*** *SKA Band 1 feed package in the laboratory at Onsala Space Observatory.*

During 2018, the room temperature Band 1 feed package prototype, developed by OSO in collaboration with industry partners, was manufactured and tested. In the final test the receiver was mounted and successfully qualification tested on a MeerKat dish in South Africa (see Fig. 5.2), after which the product passed Critical Design Review (CDR).

***Figure 5.2.*** *SKA Band1 Feed mounted on MeerKat dish during qualification tests at SARAO. Image credit: G. Smit, SARAO.*

## 5.2 SKA-WBSPF

The Wide Band Single Pixel Feed (WBSPF) consortium is aiming to develop advanced instrumentation for the future development of the SKA project. Members of the consortium are companies and universities from Sweden, Germany, France, Holland and China. The work of the consortium includes the design of wide-band feeds, LNAs and digitizers. OSO provides overall project management for the consortium. During 2018, OSO hosted the successful Preliminary Design Review (PDR) of the WBSPF and presented a first design of the two-feed system in a joint cryogenic dewar (JLRAT). The PDR included measured results from manufactured feeds and LNAs. OSO has been responsible for the development, manufacture and test of the Band B feed and tests with the LNAs. OSO also provided input on the cryogenic dewar design. The PDR outcome was very positive and has sparked a further interest in the wideband work possible for future upgrades on the SKA.

### 5.3 AENEAS

Onsala Space Observatory has been involved in the EU Horizon 2020 project AENEAS since the beginning of 2017. The aim of the project is to propose a model for a European Science Data Centre (ESDC), which will support the European astronomy community in processing SKA data products. OSO is the lead partner of a task within one of the work packages, which focuses on the evaluation of existing data transfer protocols and storage subsystems.

## 6 Computers and networks

*[Module 10]*

During 2018 the local Onsala cluster was upgraded from four machines with 48 cores together with 100 TB of data storage, with five machines with a total of 112 cores and 223 TB of data storage. Also during 2018 the larger OSO owned cluster at the SNIC–C3SE node at Chalmers consisting of 5 machines with a total of 100 cores, additionally 2 machines each have 2 GPUs, has been upgraded with another cluster consisting of 5 machines with a total of 160 cores. Both clusters share a 100 TB Lustre file-disk system plus 196 TB of slower disk storage. This storage is dimensioned to allow an international LOFAR data set (40 TB) plus two large ALMA data sets (20 TB) to be processed (including scratch space) on the Lustre file system. A set of data storage systems in Onsala used operationally for the temporary storage of raw VLBI data consists of four machines with a total capacity of 1.0 PB and 48 cores.

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]*

The radio spectrum is a limited resource, under ever increasing pressure for frequency allocations by active (i.e., emitting) users. On behalf of European radio astronomers, the Committee on Radio Astronomy Frequencies (CRAF, 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 chairman and a secretary, and it employs a full-time Frequency Manager. Sweden is represented in CRAF via OSO. In addition, OSO is also contributing to the expenses of the CRAF Frequency Manager, currently stationed in Munich, Germany. CRAF is represents European Radio astronomy at international meetings where possible threats to radio astronomy occur. In 2018, the activities have continued in preparation for the 2019 ITU World Radio Communication Conference in Sharm el-Sheikh Egypt, 28 October to 22 November 2019. The OSO CRAF member focuses also on interference issues at local and national levels (via contacts with Post- och telestyrelsen, PTS). Examples of issues during 2018 have concerned the OTT registration at ITU (as well as updates for the 20 and 25 m telescopes), coordination zones for the bands 2300-2380 MHz and 3400-3800 MHz and preparation for 5th generation (5G) mobile network coordination.

# 8 Memberships of International Committees

During 2018 OSO was represented on the following international boards and coordinating committees. The observatory Director John Conway serves on many of these boards.

- *AENEAS,* an EU-financed Horizon 2020 project to develop a concept and design for a distributed, European Science Data Centre for SKA (the Director is a board member)
- *The European VLBI Network (EVN)* for astronomical VLBI (the Director is the 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 board member)
- *The APEX project* where three partners operate a 12 m sub-mm telescope 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)
- *RadioNet,* an EU-financed Horizon 2020 project, which coordinates all of Europe's leading radio astronomy facilities (The Director is a board member, Michael Lindqvist is leading the Networking Activity Dissemination)
- *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; In addition, Hans Olofsson is a member of the Finance Committee)
- *SKA Dish Design Consortium* (the Director is a board member)
- *SKA Wide-Band Single Pixel Feed Design Consortium* (the Director is the leader of the Consortium)
- *SKA communications steering committee* (Robert Cumming is a member)
- *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 a board member)
- *International Earth Rotation and Reference Frame Service (IERS*) (Rüdiger Haas is a board and committee member)
- *The European VLBI Group for Geodesy and Astrometry (EVGA*) (Rüdiger Haas is Chairman)
- *Galileo Scientific Advisory Committee (GSAC) of the European Space Agency* (Gunnar Elgered is chairman)
- *ESF Committee on Radio Astronomy Frequencies (CRAF)* for the protection of the radio band for radio astronomical use (Michael Lindqvist is a committee member and a member of the management team)

# 9 EU projects

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

OSO participates in four EU Horizon 2020 projects (proposals submitted in 2016 and 2017): RadioNet, AENEAS, JUMPING JIVE and LOFAR4SW.

## 9.1 RadioNet

RadioNet joins together 28 partners, amongst them institutions operating world-class radio telescopes, as well as organisations performing cutting-edge research, education, and development in a wide range of technology fields that are important for radio astronomy. OSO is part of the Transnational Access (TA) program via APEX and the EVN, and participates in the Networking Activities. OSO also plays an important role in all three of its Joint Research Activities (JRA) which includes both software and hardware development. RadioNet includes the following JRAs:

- *Advanced European Technologies for Heterodyne Receivers for Astronomy (AETHRA)* aims at exploiting new technologies, such as highly integrated microelectronic semi- or superconducting circuits, to significantly improve the next generation receivers of mm and sub-mm wavelength telescopes, reinforcing European technological and scientific leadership by considerably improving the receiver performance and observing speed of the European-owned world leading facilities ALMA, APEX, NOEMA and PV. (See also Sect. 4.7.)

- *BRoad bAND EVN (BRAND EVN)* will develop and build a prototype broad-band digital receiver, which will cover a frequency range from 1.5 GHz to 15.5 GHz. The BRAND receiver when deployed at a majority of EVN telescopes will catapult EVN to new levels of performance not achievable with any other astronomical VLBI network. The BRAND receiver might even become the next generation VGOS receiver due to its superior sensitivity, its wider bandwidth, and the possibility to choose parts of the spectrum still uncontaminated by RFI. (See also Sect. 4.3.)

- *Radio Interferometry Next Generation Software (RINGS)* will deliver advanced calibration algorithms for the next generation of radio astronomy facilities, characterized by a high sensitivity, a high bandwidth and long baselines. The functionality delivered by RINGS will be incorporated in the CASA software package. (See also Sect. 4.4.)

RadioNet started January 2017 and will run for four years (until December 2020).

## 9.2 AENEAS

The large scale, rate, and complexity of the data that the SKA will generate, present challenges in data management, computing, and networking. The objective of the Advanced European Network of E-infrastructures for Astronomy with the SKA (AENEAS) project is to develop a concept and design for a distributed, European Science Data Centre (ESDC) to support the astronomical community in achieving the scientific goals of the SKA. AENEAS brings together all the European member states currently part of the SKA project as well as potential future EU SKA national partners, the SKA Organisation itself, and a larger group of international partners

including the two host countries Australia and South Africa. (See also Sect. 5.3.) AENEAS started January 2017 and will run for three years (until December 2019).

### 9.3 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 will 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 will 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 (until January 2021).

### 9.4 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 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, interstellar scintillation measurements of densities and velocities in the inner heliosphere, and high-resolution measurements of 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 (until May 2021).

## 10 Education

The OSO national infrastructure staff do not generally take part in the academic teaching at Chalmers (except for, e.g., a few guest lectures on specialized radio astronomy observing techniques). 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 were used in astronomy 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 visited the Observatory as part of the course Experimental physics. Additionally, students from the universities in Stockholm and Lund visited the Observatory during 2018 to carry out observations and/or to learn about radio astronomy.

# 11 Outreach

Outreach activities at OSO are not part of the VR funded national infrastructure but are funded entirely by Chalmers. During 2018 over 1400 people visited Onsala Space Observatory, its telescopes and exhibition. Most came as part of a total of 40 guided tours, of which school groups of all ages accounted for 22 of the tours. Around 300 of these visitors to Onsala came as part of two public open days, during the Gothenburg Science Festival and on the Mothers' day open day in May. In conjunction with Mothers' day we organised for the second year running a special event for the observatory's closest neighbours in the village of Råö. In August Chalmers was host to Rymdforskarskolan, a summer school for high school students interested in space and astronomy, organised by Astronomisk Ungdom (the Swedish Astronomical Youth Association). Several staff members contributed with guest lectures and labs, and a whole day visit to the observatory in Onsala.

In August Chalmers was host to Rymdforskarskolan, a summer school for high school students interested in space and astronomy, organised by Astronomisk Ungdom (the Swedish Astronomical Youth Association). Several staff members (also from GARD) contributed with guest lectures and labs, and a whole day visit to the observatory in Onsala.

Our SALSA radio telescopes were booked for an average of nearly 23 hours per week, on average 3.5 h per booking, by students, teachers and amateur astronomers from 14 countries. This includes Sweden but also from as far away as the US, Vietnam and Sri Lanka. Most users study the movements of interstellar gas in the Milky Way. We provided supervision for Swedish high school projects using SALSA. SALSA was used to demonstrate and teach radio astronomy to the general public in multiple outreach activities, both in Onsala and elsewhere.

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 delivery of the Band 1 receiver for SKA to South Africa, how radio telescopes carried out precision followup of the neutron star collision discovered by gravitational wave detector LIGO, and on new ways of using methanol molecules to investigate magnetic fields in space.

The staff handled many media enquiries on astronomical topics and were regularly quoted in news media. We also supported department scientists who gave a number of public talks during the year, particularly on Sweden's Day and Night of Astronomy in September, at events in Gothenburg and other locations.

We participated in the conference Communicating Astronomy with the Public in Fukuoka, Japan. Both there and in Sweden and Italy Daria Dall'Olio developed and presented her project about using Japanese manga and anime culture to communicate astronomical concepts to young people.

In collaboration with Chalmers's fundraising office, Chalmersfastigheter and our host department, we continued planning for a new visitor centre at the observatory. A prestudy was successfully completed and followed by more detailed planning activities both for the building and a new exhibition.

# 12 Changes in organisation

*[Module 1]*

Eva Wirström was appointed Deputy director of the OSO infrastructure, starting 1 December 2018. Eva previously belonged to the Astronomy and Plasma Physics Division at SEE. Eva was also appointed Head of the OSO Division at Department of Space, Earth and Environment (SEE) and is primarily responsible within the Chalmers university structure for staff and other

administration issues. John Conway remains Division Scientific Director and directly reports to VR and the OSO Steering group concerning OSO infrastructure activities.

The Steering Committee, chaired by Kjell Möller, continued its work during 2018. Floriana Lombardi (Chalmers) resigned from the committee after six years of service. New members of the committee are Merja Tornikoski (Aalto University Metsähovi Radio Observatory) and Christian Forssén (Chalmers).

The OSO Time Allocation Committee (TAC) handles proposals for observing time on the Onsala 20 m telescope (single-dish), Swedish APEX time, and the Onsala LOFAR station (stand-alone). The TAC continued its work during 2018. Michael Olberg (Chalmers) resigned from the committee after eight years of service, and was replaced by Jouni Kainulainen (Chalmers).

The memberships of the Steering Committee and the Time Allocation Committee can be found at http://www.chalmers.se/en/centres/oso/about-us/Pages/Organization.aspx.

# 13 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.

# 14 Importance to industry

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. It is expected that the SKA will have a large financial payback to Swedish industry especially if Sweden fully joins the SKA construction phase. OSO is working closely with industrial partners (Leax Arkivator and Low Noise Factory) within the SKA project (see Sect. 5). Similar technology has possible commercial applications for geodetic and astronomical VLBI. Till the end of November 2018 Kjell Möller, chairman of the OSO Steering committee, served as the Swedish SKA Industrial Liaison Officer (ILO). From December 2018 Patrik Carlsson of Chalmers Industrial Technology and Big Science Sweden took over the SKA ILO role. Big Science Sweden (https://www.bigsciencesweden.se) is a new organisation which promotes technological and industrial return to Sweden from international Big Science infrastructures.

# Acronyms

| | |
|---|---|
| A&A | Astronomy & Astrophysics (a scientific journal) |
| AENEAS | Advanced European Network of E-infrastructures for Astronomy with the SKA |
| 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 |
| AIP | Advanced Instrumentation Programme (SKA) |
| 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 |
| CO | Carbon monoxide (molecule frequently observed by radio telescopes) |
| CoI / Co-I | Co-investigator |
| CRAF | Committee on Radio Astronomy Frequencies (ESF) |
| DBBC | Digital Base Band Converter (equipment for VLBI observations) |
| EC | European Commission |
| ERIC | European Research Infrastructure Consortium |
| ESDC | European Science and Data Centre (SKA) |
| ESF | European Science Foundation |
| ESO | European Southern Observatory |
| EUREF | IAG Reference Frame Sub-Commission for Europe |
| e-VLBI | electronic VLBI (fibre optics connect radio telescopes to a central data processor, which correlates the data from the telescopes in real-time) |
| EVGA | The European VLBI Group for Geodesy and Astrometry |
| EVN | European VLBI Network |
| 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 |
| HEB | Hot Electron Bolometer |
| HST | Hubble Space Telescope |
| IAG | The International Association of Geodesy |
| IAU | International Astronomical Union |
| ICSU | International Council for Science |

| | |
|---|---|
| IERS | International Earth Rotation and Reference Frame Service |
| IF | Intermediate frequency |
| IGETS | International Geodynamics and Earth Tide Service |
| IGS | The International GNSS Service |
| ILO | Industrial Liaison Officer |
| ILT | International LOFAR Telescope |
| IRDC | Infrared Dark Cloud |
| 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) |
| LNA | Low-Noise Amplifier |
| LOFAR | Low Frequency Array |
| LOFAR4SW | LOFAR for Space Weather (EU Horizon 2020 project) |
| MC2 | Department of Microtechnology and Nanoscience at Chalmers |
| MNRAS | Monthly Notices of the Royal Astronomical Society (a scientific journal) |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| NOVA | Nederlandse Onderzoekschool Voor Astronomie (The Netherlands Research School for Astronomy) |
| 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 *or* Rådet för forskningens infrastrukturer vid VR (The Council for Research Infrastructures at VR) |
| RINGS | Radio Interferometry Next Generation Software (part of RadioNet) |
| RISE | Research Institutes of Sweden |
| SALSA | Small antennas at OSO for education and outreach |
| SB | Scheduling Block (ALMA) |
| SCG | Superconducting Gravimeter |
| SEE | Department of Space, Earth and Environment (OSO 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 |
| 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 |
| SP | Technical Research Institute of Sweden (now part of RISE) |
| 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 |
| UT1 | The principal form of Universal Time (which is based on Earth's rotation) |
| UTC | Coordinated Universal Time (an atomic timescale that approximates UT1) |
| VGOS | VLBI Geodetic Observing System |
| VLBI | Very Long Baseline Interferometry |
| VR | Vetenskapsrådet, The Swedish Research Council |
| WBSPF | Wideband Single Pixel Feeds |
| WDS | World Data System, an Interdisciplinary Body of the International Council for Science (ICSU) |
| WP | Work Package |

# Publications 2018

This document lists publications in refereed journals 2018 enabled by the Onsala infrastructure, divided by instrument and separated in two groups: with or without a Swedish author. 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.

- **ALMA** observations, publications with Nordic authors (69/42) *(total/Swedish)*
- **APEX** observations (all APEX partners' observing time) (78/14)
- **Astronomical VLBI** observations with EVN and GMVA, or using JIVE (20/4)
- **LOFAR** observations (58/13)
- **Geoscience** (OSO instruments specifically stated) (27/4)
- **Onsala 20 m telescope, single-dish** observations (4/1)
- **Technical** publications about, e.g., receiver development, by OSO staff (6)

***In addition*** to the publications listed below, in 2018 there was *one* publications using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), and *four* publications using data from *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.

*Acronyms:*

| | |
|---|---|
| A&A | Astronomy & Astrophysics |
| AJ | Astonomical Journal |
| ApJ | Astrophysical Journal |
| MNRAS | Monthly Notices of the Royal Astronomical Society |
| PASP | Publications of the Astronomical Society of the Pacific |

## ALMA,
## publications in refereed journals 2018, with Nordic authors

### Swedish authors (ALMA)

*The 30 Year Search for the Compact Object in SN 1987A.*
Alp, Dennis; Larsson, Josefin; Fransson, Claes; Indebetouw, Remy; Jerkstrand, Anders; Ahola, Antero; Burrows, David; Challis, Peter; Cigan, Phil; Cikota, Aleksandar; Kirshner, Robert P.; van Loon, Jacco Th.; Mattila, Seppo; Ng, C. -Y.; Park, Sangwook; Spyromilio, Jason; Woosley, Stan; Baes, Maarten; Bouchet, Patrice; Chevalier, Roger; Frank, Kari A.; Gaensler, B. M.; Gomez, Haley; Janka, Hans-Thomas; Leibundgut, Bruno; Lundqvist, Peter; Marcaide, Jon; Matsuura, Mikako; Sollerman, Jesper; Sonneborn, George; Staveley-Smith, Lister; Zanardo, Giovanna; Gabler, Michael; Taddia, Francesco; Wheeler, J. Craig, ApJ 864, 174 (2018)

*Magnetic field in a young circumbinary disk.*
Alves, F. O.; Girart, J. M.; Padovani, M.; Galli, D.; Franco, G. A. P.; Caselli, P.; Vlemmings, W. H. T.; Zhang, Q.; Wiesemeyer, H., A&A 616, A56 (2018)

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## Geoscience,
## Publications in refereed journals 2018, OSO instruments specifically stated

### Swedish authors (Geoscience)

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### International authors (Geoscience)

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Landskron, D., Böhm, J., J. Geod. 92, 1387 (2018)

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Titov, O.A.; Lopez, Y.R., Astronomy Letters – A Journal of Astronomy and Space Astrophysics, 44(3), 139 (2018)

*Testing general relativity with geodetic VLBI What a single, specially designed experiment can teach us.*
Titov, O.; Girdiuk, A.; Lambert, S.B.; Lovell, J.; McCallum, J.; Shabala, S.; McCallum, L.; Mayer, D.; Schartner, M.; de Witt, A.; Shu, F.; Melnikov, A.; Ivanov, D.; Mikhailov, A.; Yi, S.; Soja, B.; Xia, B.; Jiang, T., A&A 618, A8 (2018)

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**Swedish authors (OSO 20 m)**

*Sulphur-bearing molecules in AGB stars. II. Abundances and distributions of CS and SiS.*
Danilovich, T., Ramstedt, S., Gobrecht, D., Decin, L., De Beck, E., Olofsson, H., A&A 617, A132 (2018)

**International authors (OSO 20 m)**

*2018 Census of Interstellar, Circumstellar, Extragalactic, Protoplanetary Disk, and Exoplanetary Molecules.*
McGuire, Brett A., ApJS 239, 17 (2018)

*A search for evidence of small-scale inhomogeneities in dense cores from line profile analysis.*
Pirogov, Lev, Res. Astron. Astrophys. 18, 100 (2018)

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Ryabukhina, Olga L.; Zinchenko, Igor I.; Samal, Manash R.; Zemlyanukha, Petr M.; Ladeyschikov, Dmitry A.; Sobolev, Andrej M.; Henkel, Christian; Ojha, Devendra K., Res. Astron. Astrophys. 18, 095 (2018)

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*ALMA Band 5 receiver cartridge: Design, performance, and commissioning.*
Belitsky, V.; Bylund, M.; Desmaris, V.; Ermakov, A.; Ferm, S. -E.; Fredrixon, M.; Krause, S.; Lapkin, I.; Meledin, D.; Pavolotsky, A.; Rashid, H.; Shafiee, S.; Strandberg, M.; Sundin, E.; Yadranjee Aghdam, P.; Hesper, R.; Barkhof, J.; Bekema, M. E.; Adema, J.; de Haan, R.; Koops, A.; Boland, W.; Yagoubov, P.; Marconi, G.; Siringo, G.; Humphreys, E.; Tan, G. H.; Laing, R.; Testi, L.; Mroczkowski, T.; Wild, W.; Saini, K. S.; Bryerton, E., A&A 611, A98 (2018)

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Belitsky, V.; Lapkin, I.; Fredrixon, M.; Meledin, D.; Sundin, E.; Billade, B.; Ferm, S. -E.; Pavolotsky, A.; Rashid, H.; Strandberg, M.; Desmaris, V.; Ermakov, A.; Krause, S.; Olberg, M.; Aghdam, P.; Shafiee, S.; Bergman, P.; De Beck, E.; Olofsson, H.; Conway, J.; De Breuck, C.; Immer, K.; Yagoubov, P.; Montenegro-Montes, F. M.; Torstensson, K.; Pérez-Beaupuits, J. -P.; Klein, T.; Boland, W.; Baryshev, A. M.; Hesper, R.; Barkhof, J.; Adema, J.; Bekema, M. E.; Koops, A., A&A 612, A23 (2018)

*Optimization and Realization of Quadruple-Ridge Flared Horn With New Spline-Defined Profiles as a High-Efficiency Feed From 4.6 GHz to 24 GHz*.
Dong, Bin; Jian Yang; Jens Dahlström; Jonas Flygare; Miroslav Pantaleev; Bhushan Billade, IEEE Transactions on Antennas and Propagation 67, 585 (2018)

*Suspended GaN beams and membranes on Si as a platform for waveguide-based THz applications*.
Krause, S.; V. Desmaris; A. Pavolotsky; D. Meledin; V. Belitsky, J. Micromech. Microeng. 28, 105007 (2018)

*Noise and IF Gain Bandwidth of a Balanced Waveguide NbN/GaN Hot Electron Bolometer Mixer Operating at 1.3 THz*.
Krause, Sascha; Denis Meledin; Vincent Desmaris; Alexey Pavolotsky; Hawal Rashid; Victor Belitsky, IEEE Transactions on Terahertz Science and Technology 8, 365 (2018)

*A Proposed Heterodyne Receiver for the Origins Space Telescope.*
Wiedner, Martina C.; Imran Mehdi; Andrey Baryshev; Victor Belitsky; Vincent Desmaris; Anna Maria DiGiorgio; Juan-Daniel Gallego; Maryvonne Gerin; Paul Goldsmith; Frank Helmich; Willem Jellema; André Laurens; Christophe Risacher; Asantha Cooray; Margaret Meixner; and the Origins Space Telescope (OST) Study Team, IEEE Transactions on Terahertz Science and Technology 8, 558 (2018)

## Key numbers (nyckeltal)

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

**Infrastrukturens namn:** OSO
**Diarienummer:** 2017-00648
**Respondent (namn):** John Conway
**Respondent (epost):** john.conway@chalmers.se
**Respondent (telefon):** 031-772 5503
**Avser år:**

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

| **1** | Anställda vid infrastrukturen | |
|---|---|---|
| 1.1 | *Enskilda individer* | |
| | Totalt | 57 |
| | Astro user support / ARCnode (Modul 2) | 8 |
| | APEX svensk tid (Modul 3) | 4 |
| | Astronomisk VLBI (Modul 4) | 4 |
| | LOFAR (Modul 5) | 2 |
| | Geovetenskap (Modul 6) | 17 |
| | Utveckling av mm-mottagare (Modul 8) | 9 |
| | Utveckling av cm-mottagare (Modul 9) | 7 |
| | Ledning (Modul 1) | 4 |
| | Övriga tjänster (Modul 10) | 4 |
| 1.2 | *FTE* | |
| | Totalt | 35,1 |
| | ALMA / ARCnode (Modul 2) | 4,5 |
| | APEX svensk tid (Modul 3) | 2,9 |
| | Astronomisk VLBI (Modul 4) | 3,5 |
| | LOFAR (Modul 5) | 0,4 |
| | Geovetenskap (Modul 6) | 6,8 |
| | Utveckling av mm-mottagare (Modul 8) | 6,3 |
| | Utveckling av cm-mottagare (Modul 9) | 6,2 |
| | Ledning (Modul 1) | 1,5 |
| | Övriga tjänster (Modul 10) | 3,0 |

**Förklaringar till tabell 2, 3 och 4:**

**ALMA:** Tabell 2: Projekt med en nordisk PI. Cycle 5 (observationer oktober 2017 - september 2018).
Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle 5.
Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal projekt.
**APEX:** Alla projekt på svensk tid. Period P101 och P102 (observationer 2018).
**Astronomisk VLBI:** Alla proposaler inskickade 2018. Alla observationer utförda 2018.
**LOFAR:** Alla projekt i Cycle 9 och 10 (observationer november 2017 - november 2018), samt Onsala single station 2018.

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

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

Gråmarkerade fält är inte aktuella för OSO.

| | | a. Alla projekt | | | b. Typ av hemvist för alla PI | | | | | | c. Typ av akademisk hemvist för PI (endast akademiska hemvister) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Akademisk | | | Kommersiell | Offentlig | Övriga | | | |
| **2** | Projekt | Totalt | Män | Kvinnor | Totalt | Män | Kvinnor | Totalt | Totalt | Totalt | Chalmers | Annat svenskt lärosäte | Internationell |
| 2.1 | *Sökta projekt* | | | | | | | | | | | | |
| | Totalt | 302 | 216 | 86 | 302 | 216 | 86 | | | | 50 | 10 | 242 |
| | ALMA (projekt med nordisk PI) | 72 | 46 | 26 | 72 | 46 | 26 | | | | 39 | 6 | 27 |
| | APEX svensk tid | 36 | 18 | 18 | 36 | 18 | 18 | | | | 4 | 3 | 29 |
| | Astronomisk VLBI | 119 | 96 | 23 | 119 | 96 | 23 | | | | 3 | 0 | 116 |
| | LOFAR | 75 | 56 | 19 | 75 | 56 | 19 | | | | 4 | 1 | 70 |
| 2.2 | *Genomförda projekt* | | | | | | | | | | | | |
| | Totalt | 139 | 98 | 41 | 139 | 98 | 41 | | | | 19 | 10 | 110 |
| | ALMA (projekt med nordisk PI) | 22 | 17 | 5 | 22 | 17 | 5 | | | | 11 | 6 | 5 |
| | APEX svensk tid | 25 | 11 | 14 | 25 | 11 | 14 | | | | 3 | 3 | 19 |
| | Astronomisk VLBI | 29 | 25 | 4 | 29 | 25 | 4 | | | | 1 | 0 | 28 |
| | LOFAR | 63 | 45 | 18 | 63 | 45 | 18 | | | | 4 | 1 | 58 |

| | | d. Alla användare | | | e. Typ av hemvist för alla användare | | | | | | f. Typ av akademisk hemvist för användare (endast akad. hemvister) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Akademisk | | | Kommersiell | Offentlig | Övriga | | | |
| **3** | Användare | Totalt | Män | Kvinnor | Totalt | Män | Kvinnor | Totalt | Totalt | Totalt | Chalmers | Annat svenskt lärosäte | Internationell |
| 3.1 | *Sökta projekt* | | | | | | | | | | | | |
| | Totalt | 969 | 721 | 248 | 969 | 721 | 248 | | | | 51 | 41 | 877 |
| | ALMA (nordiska användare, alla projekt) | 121 | 87 | 34 | 121 | 87 | 34 | | | | 36 | 35 | 50 |
| | APEX svensk tid | 165 | 109 | 56 | 165 | 109 | 56 | | | | 22 | 6 | 137 |
| | Astronomisk VLBI | 499 | 398 | 101 | 499 | 398 | 101 | | | | 7 | 1 | 491 |
| | LOFAR | 293 | 204 | 89 | 293 | 204 | 89 | | | | 10 | 5 | 278 |
| 3.2 | *Genomförda projekt* | | | | | | | | | | | | |
| | Totalt | 631 | 450 | 181 | 631 | 450 | 181 | | | | 37 | 32 | 562 |
| | ALMA (nordiska användare, alla projekt) | 86 | 61 | 25 | 86 | 61 | 25 | | | | 29 | 25 | 32 |
| | APEX svensk tid | 140 | 91 | 49 | 140 | 91 | 49 | | | | 22 | 6 | 112 |
| | Astronomisk VLBI | 186 | 148 | 38 | 186 | 148 | 38 | | | | 1 | 0 | 185 |
| | LOFAR | 274 | 190 | 84 | 274 | 190 | 84 | | | | 10 | 5 | 259 |

| | | g. Total kvantitet per typ av tillgång till infrastrukturen | | | h. Kvantitet av tillgång för akademiska projekt | | |
|---|---|---|---|---|---|---|---|
| | | Alla användare | | | Fysisk tillgång till infrastruktur | | |
| **4** | Typ och kvantitet av tillgång | Fysisk | Data | Prover | Totalt | Män | Kvinnor |
| 4.1 | *Användning under året* | | | | | | |
| | Totalt | n/a | | | n/a | n/a | n/a |
| | ALMA (antal nordiska projekt) | 22 | | | 22 | 17 | 5 |
| | APEX svensk tid (h) | 439 | | | 439 | 231 | 208 |
| | Astronomisk VLBI (h) | 572 | | | 572 | 488 | 84 |
| | LOFAR (h) | 5161 | | | 5161 | 4580 | 581 |
| | Geodetisk VLBI (h) | 1264 | | | 1264 | n/a | n/a |

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