Report on the activities in 2016 of

Onsala Space Observatory
The Swedish National Facility for Radio Astronomy

This report presents the activities at Onsala Space Observatory (OSO) during 2016, 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.

ALMA’s close-up view of the centre of galaxy NGC 1377 reveals a swirling jet. In this colour-coded image (middle), reddish gas clouds are moving away from us, bluish clouds towards us, relative to the galaxy’s centre. The ALMA image shows light with wavelength around one millimetre from molecules of carbon monoxide (CO). A cartoon view (right) shows how these clouds are moving, this time seen from the side. Image credit: CTIO/H. Roussel et al./ESO (left panel); Alma/ESO/NRAO/S. Aalto (middle panel); S. Aalto (right panel).

Onsala, 12th April 2017

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1 Operations

During 2016 Onsala Space Observatory (OSO) operated the following facilities:

- The Onsala 20 m telescope for astronomical Very Long Baseline Interferometry (VLBI), geodetic VLBI, and single-dish astronomy
- The Onsala 25 m telescope for astronomical VLBI
- The Onsala LOFAR station as part of the International LOFAR Telescope (ILT) and in stand-alone mode
- The Atacama Pathfinder Experiment telescope (APEX) for single-dish astronomy
- The Nordic ARC node (the Atacama Large Millimeter/sub-millimeter Array Regional Centre node for the Nordic, and Baltic, countries)
- 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$_2$O, CO, and O$_3$ in the middle atmosphere
- The Onsala seismometer station
- The Onsala time & frequency laboratory
Operations using the above facilities are described in more detail below under Telescopes (Section 1.1), Nordic ARC node (Section 1.2), and Geophysical instruments (Section 1.3), respectively.

1.1 Telescopes

[Modules: national A4 and A5, international A1, A2 and A3]

In general, all telescopes have operated according to the 2016 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 2016 activity plan without any major divergence. This included 53 geodetic campaigns, 26 astronomical single-dish projects, participation in 4 extended astronomical VLBI sessions, 2 teaching/outreach observations, and a number of shorter special campaigns in collaboration with international telescopes. Maintenance (incl. technical observations) occurred at anticipated levels. In addition, a few weeks in the autumn were spent on installing and commissioning dual sideband capabilities at 3&4 mm, as well as increasing the receiver bandwidth at 18–50 GHz to 4 GHz.

– **Onsala 25 m telescope:** The Onsala 25 m telescope has operated according to the 2016 activity plan without any major problems during the year.

– **APEX:** A total of 58 days, organized in five runs, of Swedish APEX observations were carried out in 2016. To perform service mode observations, which are organized as three observing shifts per day (afternoon, night, morning), OSO typically sent four observers per run.

  In February of 2016, an ALMA Band 9 receiver for the frequency band 600–722 GHz was installed into the SEPIA cartridge at APEX. Shortly afterwards, a Call for science verification proposals for the new SEPIA-B9 receiver went out to the Swedish community. Accepted projects were observed in June and August. SEPIA-B9 was offered as a regular PI instrument in the Call for proposals for the P98 period, with the first regular observations carried out in August.

– **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]. 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 ways:

- The Onsala 20 m telescope:  
  - 73 days of single-dish astronomy  
  - 32 days of astronomical VLBI  
  - 53 days of geodetic VLBI  
- The Onsala 25 m telescope:  
  - 66 days of astronomical VLBI  
- The LOFAR station:  
  - 205 days (ILT), 158 days (local)  
- APEX telescope:  
  - 58 days of single-dish astronomy

Note that time for “normal” technical service, pointing, etc. are not included in the above figures. These service activities amounted to about 22 and 13 days on the 20 m and 25 m telescopes, respectively. Test observations of commissioning type are not included.

1.2 Nordic ARC Node
[Module: national As]

In 2016, the Nordic ARC provided support to the Nordic ALMA communities for data reduction and analysis of ALMA data from all observing cycles. Additionally, proposal preparation workshops were organized for the Cycle 4 call for proposals. Basic two-day ALMA proposal workshops were held at Onsala Space Observatory and Stockholm University. The workshops contained sessions focused on scientific results obtained with ALMA by the Nordic community, and tutorials in the tools necessary for proposal preparation.

In Cycle 4, 65 % of all (69) Swedish co-I/PI were awarded time. Swedish co-I/PI are represented at 117 out of a total of 707 accepted ALMA proposals. The Nordic ARC provided contact scientists for each project with a Nordic PI or leading Nordic co-I. In 2016, contact scientists were assigned for 29 projects. 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 staff also supported several face-to-face visits for data reduction of 13 Cycle 1, 2, and 3 ALMA proposals (with Nordic PIs or co-Is). Each project has taken an average of two weeks of full-time support and so far at least 75 % of all Nordic projects with delivered data have benefited from Nordic ARC face-to-face support.

The Nordic ARC performed quality assessment on 59 European ALMA observations units, each containing several scheduling blocks (SBs). The majority (>90 %) of these processed SBs were for Nordic projects. Thus, the Nordic ARC performed quality assessment for approximately 10 % of all European delivered data sets.

In March the deputy ARC node manager attended the ARC node representatives face-to-face meeting in Prague. 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 Portugal. 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. In October the ARC node hosted a Band 5 busy week. During this week ARC node staff, together with ESO staff and members of other ARC nodes, reduced the science verification observations with ALMA in Band 5, and developed the reduction scripts and guides. Finally, ARC node staff was involved in the commissioning of VLBI observations.

The ARC Node continued the development and maintenance of the Advanced Data Analysis Tools, published at the Nordic ARC webpage (http://www.oso.nordic-alma.se/software-tools.php). Since the release of the UVMULTIFIT code (in early 2014), a total of 21 users have contacted the Node for support in the use of the tool and/or to ask for new
features (e.g., non-algebraic Fourier transforms, absolute astrometry, etc.), which have been implemented. The maintenance of the ALMA packaging script (developed at the Node and used by the whole ALMA project to arrange the datasets prior to ingestion into the archive) has been further maintained and updated. Other advanced tools (e.g., simulation of ALMA spectro-polarimetric observations) have also been developed to support proposal preparation in ALMA Cycle 4. The "APSYNSIM" graphical simulator was also used in several radio astronomy schools across Europe, receiving very positive feedback (there have been more than 650 registered downloads from the release of the first version, in early 2015).

1.3 Geophysical instruments

The geodetic VLBI observing sessions, using the 20 m telescope, are 24 h long and include regular IVS sessions in the R1-, RD-, RDV-, T2- and EUR-series. In total, 53 sessions in the IVS program were observed during 2016. All sessions were recorded with the DBBC/Mark5B+ system in parallel with the mk5b-format on the FlexBuff. These data were then e-transferred to the respective correlator. For a few sessions, the Flexbuff recording failed and thus the data recorded on Mark5B-modules were read out and thereafter e-transferred to the correlator.

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 2016. 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 in the same networks network (more details in Section 2.2 below).

- **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 was operated continuously over the year with a temporal resolution of one minute. No data were missing.

  The GNSS-based tide gauge was also operated continuously 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. Astrid was operating continuously from February until and including November except for July, and Konrad was operating continuously from May until and including December.

- **Aeronomy station:** The aeronomy station performed continuous observations of CO, O₃, and H₂O in the middle atmosphere (except for short maintenance periods).
- **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, which contributes to the universal atomic time. OSO also collaborates with SP Technical Research Institute of Sweden on a Swedish time-keeping system. SP owns a second hydrogen maser and a cesium clock that are installed at Onsala. These 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: national A3, A4 and A5, international A1, A2 and A3]

In this compilation of user statistics for astronomy, ‘user’ means an author or co-author of a proposal granted observing time during 2016 on an OSO instrument. The numbers of *unique users* are reported, i.e., an individual using a telescope for two or more projects is only counted once.

For *ALMA*, the user statistics are given for Proposal Cycle 4 with deadline in April 2016. Only Swedish ALMA users are reported here.

The number of *APEX* users is only for the Swedish APEX time.

*Astro VLBI* includes users of EVN and GMVA.

**Number of users per higher education institution:**
A majority of the Swedish users were from Chalmers University of Technology. Of the non-Chalmers users, a significant fraction was affiliated with Stockholm University, but there were also users from the Royal Institute of Technology, Lund University and Uppsala University.

- Chalmers University of Technology: 44 users
- Stockholm University: 20 users
- Royal Institute of Technology: 2 users
- Lund University: 2 users
- Uppsala University: 1 user

The 549 international users were from a large number of universities and research institutes. We choose not to list them all here, but instead note that they represented institutes in the following 32 countries (with those with the highest number of users listed first): Netherlands, Germany, United Kingdom, United States of America, Italy, France, Chile, Spain, Russia, Poland, Australia, Belgium, Japan, Canada, Mexico, India, China, Denmark, South Korea, Finland, Croatia, Latvia, South Africa, Ukraine, Hungary, Albania, Austria, Greece, Iceland, Israel, Switzerland and Taiwan.

**Number of users per subject area:**
All 69 Swedish users and 549 international users did research in the subject area *103 Physical Sciences*. 
Gender balance:
Of the 549 unique non-Swedish users, 419 were men and 127 were women (for three users, the gender is unknown to us). Of the 69 unique Swedish users, 50 were men and 19 were women. The Swedish user gender balance is thus somewhat better than that for non-Swedish users. The numbers of male/female unique Swedish users of each telescope are given below:

- ALMA: 34/11 (male/female; only Swedish)
- APEX, Swedish time: 15/10
- Astronomical VLBI: 13/1
- LOFAR: 5/1
- LOFAR, stand alone: 0/0
- 20 m telescope, single dish: 17/8

Number of users per telescope:
For each telescope, two numbers are given below: the total number of users and the number of Swedish users.

- ALMA: 2560/45 (total/Swedish)
- APEX, Swedish time: 227/25
- Astronomical VLBI: 171/13
- LOFAR: 157/6
- LOFAR, stand alone: 5/0
- 20 m telescope, single dish: 62/25

Number of publications and patents:
The list below gives the number of papers in refereed journals published in 2016. 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 in which the Nordic ARC node helped the authors with observation preparation or with data reduction are given. The numbers for astronomical VLBI includes observations with EVN and GMVA, and use of JIVE. A publication list is found at the end of this report.

- ALMA: 20/19 (total/Swedish)
- APEX: 79/10
- Astronomical VLBI: 29/6
- LOFAR: 37/13
- 20 m telescope, single-dish: 5/4

In addition, in 2016 there were two publications using astronomical data from the satellite Odin (now operating mainly in aeronomy mode), eight publications using data from SEST (closed in 2003), and eleven publications by OSO staff on radio astronomical instrumentation, methods and techniques.

We are not aware of any patents originating directly from our astronomy activities.

Number of users who have applied for access to the infrastructure, but who have not been granted access:
For APEX, eight of the projects proposed for observations in 2016 were not observed for various reasons (including, e.g., unavailability of the requested receiver). There were 40 unique users on these eight projects, 29 were men and 11 were women. Several of these users took part in other projects that were observed with APEX in 2016.

No users who applied for observing time in 2016 on the Onsala 20 m telescope were denied access.
No users who requested support from the Nordic ARC node were denied support.
For the other telescopes, we have not been able to calculate (or even define) the number
of users whose applications for access in 2016 were unsuccessful, either because we do not
have full information on applications and scheduling, or because applications can result in
observations several years after it was submitted.

2.2 Geosciences
[Module: national A2]

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. These 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 8 papers with one or more Swedish authors and 13 papers with non-Swedish
authors published during 2016 where the use of data from OSO are specifically stated. In
addition, we are convinced that there are significantly more papers, especially using GNSS
reference data from OSO via IGS/EUREF, that cannot be identified if not the OSO station is
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 data. The majority of the data are moreover 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 53 experiments,
each one with a length of 24 h and rather evenly spread over the year, were carried out during
2016.

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. Considering 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, will be many millions, i.e. everybody relying on GNSS
positioning and navigation.
**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://igscb.jpl.nasa.gov/](https://igscb.jpl.nasa.gov/), and EUREF [http://www.epncb.oma.be/](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.

Additionally, via Lantmäteriet, 4639 files were downloaded from the ONSA station, and 4891 files from the ONS1 station, by Swedish users during 2016. These files are in RINEX format for postprocessing and consist of one hour long files with 1 s temporal resolution, and one day long files with 15 s temporal resolution.

Thus, OSO provides both the national and international user communities with a robust and accurate link to the international reference frame.

**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](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. IGETS is a service under the auspices of the International Association of Geodesy (IAG). During 2016, one visit with an absolute gravimeter, Lantmäteriet's FG5, took place in June-July.

**Ocean tide loading service:**
Since 2002, OSO provides a computing service for ocean tide loading effect in application to surface displacements and gravity ([http://holt.oso.chalmers.se/loading](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 25 sources featuring 8 to 11 tide species each. In 2016, the web site had 1156 different users who placed 7,332 requests for a sum of 113,682 geographic locations – probably non-unique, but many users compare a range of models for their observing stations. The original paper detailing the computation of tide displacements and the oceanic loading effects (Scherneck, Geophys. J. Int. 106, 677, 1991) has been cited 188 times.

**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. The data of the Onsala GNSS-R tide gauge were provided to an international working group of the International Association for Geodesy (IAG) to study GNSS-R for sea level monitoring. This working group is co-chaired by Thomas Hobiger. Data were provided to international research groups working on GNSS-R for an intercomparison campaign.
Aeronomy station:
Water vapour (H₂O) profiles in the middle atmosphere, from January 2015 until September 2016, were delivered to the Network for the Detection of Atmospheric Composition Change (NDACC; see http://www.ndsc.ncep.noaa.gov).

During 2016 we have over 10 months of CO/O₃ data. The upgrade of the local oscillator together with the new FFT spectrometer will make it possible for us to use frequency switched measurements with a higher bandwidth than before. This will make it possible to expand the vertical range of O₃ profiles downwards to cover the altitude range 20–70 km. When the first time series are analysed we will apply for primary status within NDACC for the updated CO/O₃ radiometer system and thereafter the data from 2016 are submitted.

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 facilities plus some international results of high science impact that make use of OSO telescopes and/or instrumentation.

3.1 Onsala 20 m telescope single dish
[Module: national A]

**HCN observations of comets C/2013 R1 (Lovejoy) and C/2014 Q2 (Lovejoy)**

*Summary:* The previously reported observations of HCN in comet C/2013 R1 (Lovejoy) from 2013 were presented in Wirström et al. (2016), together with a detection of HCN with the new 3 mm receiver system at OSO in comet C/2014 Q2 (Lovejoy). The implied mean HCN abundance relative to water was reported to be 0.2% in R1 Lovejoy, and 0.09% in Q2 Lovejoy. The comparison in data quality between these cometary observations demonstrates the high performance of the upgraded 3 mm receiver system and its potential for future coma monitoring of relatively bright comets.

**After the Interaction: an Efficiently Star-forming Molecular Disk in NGC 5195**

*Summary:* Emission from multiple molecular species in NGC5195, a small disturbed companion galaxy to the large spiral M51, was recently mapped with the CARMA interferometer and the Onsala 20 m telescope (Figure 3.1). The results show that that NGC5195 is forming stars at a normal rate and that the filling factor of dense gas is rather low. Surprisingly, the luminosity of the CN radical is abnormally high which may be due to a buried AGN.
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Figure 3.1. Spectrum of HCN(1–0) and HCO+ from OSO 20 m telescope observations of NGC 5195 (Alatalo et al. 2016). The lines are robustly detected in the 43″ beam. These confirm the results of Kohno et al. (2002) that the HCN is weak.

3.2 Astronomical VLBI

[Modules: national A3, international A3]

No apparent superluminal motion in the first-known jetted tidal disruption event Swift J1644+5734


MNRAS 462, L66–L70 (2016)

Summary: Swift J1644+5734 is the first-known tidal disruption event (TDE) with strong evidence for a relativistic jet. Yang et al. (2016) used the EVN at 5 GHz in order to directly measure the apparent speed of the radio jet (Figure 3.2). They have achieved a statistical astrometric precision about 12 μas per epoch. This is one of the best phase-referencing measurements available to date. No proper motion has been detected. They conclude that the apparent average ejection speed between 2012.2 and 2015.2 was less than 0.3c with a confidence level of 99 per cent. This tight limit is direct observational evidence for either a very small viewing angle or a strong jet deceleration due to interactions with a dense circum-nuclear medium, in agreement with some recent theoretical studies.

Figure 3.2. The natural-weighted EVN images of the tidal disruption event Swift J1644+5734 and the phase-referencing source FIRST J1644+5736 on 2012 March 8 in the background WSRT map.


**Imaging BL Lacertae at 21 microarcsecond resolution**

J. L. Gómez, A. P. Lobanov, G. Bruni et al.

**Summary:** Gómez et al. (2016) report the first polarimetric space very long baseline interferometry (VLBI) imaging observations at 22 GHz. The source, BL Lacertae, was observed in 2013 November 10 with the RadioAstron space VLBI mission, including a ground array of 15 radio telescopes (incl. the Onsala 20 m telescope). The phasing of a group of ground-based antennas allowed them to obtain reliable ground-space fringe detections up to projected baseline distances of 7.9 Earth diameters in length. Polarization images of BL Lac are obtained with a maximum angular resolution of 21 microarcseconds, the highest achieved to date (Figure 3.3). The intrinsic de-boosted brightness temperature in the unresolved core exceeds $3 \times 10^{12}$ K, suggesting, at the very least, departure from equipartition of energy between the magnetic field and radiating particles.

![Figure 3.3.](image)

**Figure 3.3.** RadioAstron polarimetric space VLBI images of BL Lac obtained in 2013 November 10–11 at 22 GHz. From left to right, images are obtained with natural a: uniform b: and “super”-uniform c: weightings.
Discovery of periodic and alternating flares of the methanol and water masers in G107.298+5.639

M. Szymczak, M. Olech, P. Wolak, A. Bartkiewicz, M. Gawroński

Summary: Szymczak et al. (2016) present observations of the intermediate-mass young stellar object G107.298+5.639, revealing for the first time that 34.4 d flares of the 6.7 GHz methanol maser emission alternate with flares of individual features of the 22 GHz water maser (Figure 3.4). VLBI data reveal that a few components of both maser species showing periodic behaviour coincide in position and velocity and all the periodic water maser components appear in the methanol maser region of size of 360 au. The maser flares could be caused by variations in the infrared radiation field induced by cyclic accretion instabilities in a circumstellar or protobinary disc.

Figure 3.4. Map of 6.7 GHz methanol maser components (circles) in G107.298+5.639 obtained with the EVN. The triangles indicate the position of the 22 GHz water maser components reported by Hirota et al. (2008) using VERA.

3.3 LOFAR
[Modules: national A3, international A2]

Subarcsecond international LOFAR radio images of Arp 220 at 150 MHz. A kpc-scale star forming disk surrounding nuclei with shocked outflows


Summary: An international collaboration of researchers led by astronomers at Chalmers have used the SKA precursor the LOFAR telescope to obtain a radio continuum image and spectral information of the starburst galaxy Arp 220 at 150 MHz (Figure 3.5). Arp 220 is a merger with two nuclei about 1 arcsecond apart, and is well known from observations at higher frequencies.
Using the high angular resolution provided by the full international LOFAR network, it was possible to, for the first time at metre wavelengths, separate the emission from the two nuclei from their immediate surroundings. The final image was made from 44 LOFAR stations in multiple countries and reached a synthesized image resolution of 0.65\"×0.35\" and sensitivity 0.15 mJy/beam, a performance similar to the groundbreaking images of M82 published by Varenius et al. (2015).

By combining the LOFAR images with observations at higher frequencies, it is possible to map the absorption of radio emission by ionised gas in the galaxy. Both nuclei of Arp 220 are found to be significantly absorbed at LOFAR frequencies. However, LOFAR also finds elongated steep-spectrum structures extending from the nuclei. These are interpreted as outflows, which may be driven by the intense star formation in the two nuclei, known from e.g. VLBI studies of radio supernovae, but could also be powered by AGN activity.

The LOFAR images of Arp 220 also show previously unknown steep-spectrum radio emission surrounding the two nuclei. More than 80\% of the detected flux comes from this extended (6"×2.2 kpc) steep spectrum (α = −0.7) emission, likely generated by star formation (i.e. by radio supernovae and supernova remnants) in the molecular disk surrounding the two nuclei.

International LOFAR observations show great promise to detect steep spectrum outflows and probe regions of thermal absorption. Furthermore, in luminous infrared galaxies such as Arp 220, the emission detected at 150 MHz does not necessarily come from the main regions of star formation. This implies that high spatial resolution is crucial for accurate estimates of star formation rates for such galaxies at 150 MHz. This may be of importance for future surveys with e.g. LOFAR or the SKA.

Figure 3.5. Left: The 150 MHz continuum emission from Arp 220 shown in grayscale with contours plotted at \([-3,3,5,10,20,40,60,80,100,120,140,200,250,300]\)×0.15 mJy/beam. The synthesized resolution is 0.65\"×0.35\". Contours in white in darker areas and black in brighter areas. The black dots mark the GHz positions of the nuclei. Right: A sketch of a possible configuration of outflows which could explain the observed morphology. (Credit: Varenius et al. 2016)
3.4 APEX

[Modules: national A5, international A1]

Detection of 183 GHz H2O megamaser emission towards NGC 4945
Summary: The APEX telescope is an ideal pathfinder – and hence its name – for more detailed observations by interferometers like ALMA. An example of this is provided by this study where APEX is used to detect an extragalactic 183 GHz water maser in the galaxy NGC 4945 (Figure 3.6). Studied in greater detail with ALMA, this emission can reveal the structure and dynamics near the black hole at the centre of this galaxy.

Temperature structures in Galactic center clouds
K. Immer, J. Kauffmann, T. Pillai, A. Ginsburg, and K.M. Menten
A&A 595, A94 (2016)
Summary: The authors present H2CO deep observations at 218 and 291 GHz, which lets them obtain gas temperature maps of several Galactic Centre Clouds. These temperature maps show clear temperature gradients, indicating that heating mechanisms that act on the bulk of the molecular gas cannot be the main heating sources. Cosmic ray heating is only possible if the heating is non-uniform on very small scales. Comparing the line widths of the main H2CO lines at 218 and 291 GHz with the measured temperatures at selected positions in the clouds, they found a clear positive correlation between these two parameters. This indicates that turbulence plays an important role in the heating of the gas.

On the origin of C4H and CH3OH in protostellar envelopes
J. Lindberg, S.B. Charnley, and M.A. Cordiner
Summary: The authors observed C4H toward 16 protostars and, when these data are combined with a re-analysis of literature data, they find no definitive evidence for a correlation with CH3OH as previously claimed. The fact that CH3OH is detected in these sources points to the dust and gas having been heated to ∼70–100K, making the CH3OH thermally sublimate. In the sources containing a protostar this may be due to a previous short outburst. The observations support the view that CH3OH and C4H, resp., reside in warmer and cooler regions of the protostellar environment, where carbon-chain formation is respectively suppressed and enhanced.
3.5 ALMA observations supported by the Nordic ARC node.

[Module: national A3]

A precessing molecular jet signaling an obscured, growing supermassive black hole in NGC 1377

S. Aalto, F. Costagliola, S. Muller, K. Sakamoto, J.S. Gallagher, K. Dasyra, K. Wada, F. Combes, S. Garcia-Burillo, L.E. Kristensen, S. Martin, P. van der Werf, A.S. Evans, J. Kotilainen

A&A 590, A73 (2016)

Summary: A high-velocity, very collimated outflow from the nucleus of galaxy NGC 1377 was observed using high spatial resolution ALMA observations in the CO(3-2) line (Figure 3.7). The outflow is interpreted as a jet of dense molecular gas, with a projected length of about 150 parsec, powered either by a faint, charged particle-dominated radio jet, or by an accretion disk wind similar to those found towards protostars. This the first evidence for a precessing, highly collimated nuclear molecular jet.

Figure 3.7. A jet of dense molecular gas from the nucleus of galaxy NGC 1377, observed with ALMA. See also the front page of this report.

Resolved images of a protostellar outflow driven by an extended disk wind


Nature 540, 406 (2016)

Summary: Observations of CO emission lines towards the proto-stellar system TMC1A revealed a spatially resolved jet that is launched by an extended disk wind from a disk (in Keplerian rotation) surrounding the protostar. The jet removes angular momentum from the system – a critical ingredient in forming stars from collapsing molecular clouds. Prior to the ALMA observations the underlying mechanism was not understood.

A detailed view of the gas shell around R Sculptoris with ALMA


Summary: The mass-loss rate evolution from the asymptotic giant branch (AGB) star R Scl is investigated using CO observations obtained with ALMA and single-dish telescopes. The ALMA observations clearly resolve the shell around the star, and the spiral shape induced by a binary companion. The shell was created during a thermal pulse approximately 2000 years ago.
Contrary to previous assumptions, the new observations show that the mass-loss rate does not decline sharply after the thermal pulse, but has a more gradual decline to its present-day value. This mass-loss rate evolution is probed by the different angular scales provided by ALMA and the single-dish observations. A gradual decline in the mass loss may cause the star to lose significantly more mass during a thermal pulse cycle, affecting the star’s lifetime on the AGB and hence the contribution of new elements to the interstellar medium.

3.6 Geosciences

A new release of the International Terrestrial Reference Frame modelling nonlinear station motions
Z. Altamimi, P. Rebischung, L. Métivier, and C. Xavier
J. Geophys. Res. Solid Earth, 121, 6109 (2016)
Summary: An updated and improved version of the International Terrestrial Reference Frame (ITRF) was derived. The analysis uses an enhanced modelling of non-linear station motions, including seasonal and post-seismic deformations. The ITRF processing includes long time series of VLBI, Global Navigation Satellite System (GNSS), Satellite Laser Ranging (SLR) and Doppler orbitography and radio-positioning integrated by satellite (DORIS). The fundamental geodetic stations, among them OSO, where precise and accurately monitored local-ties allow combining the data of the different space geodetic techniques, are of major importance in this work.

Ultra-rapid earth rotation determination with VLBI during CONT11 and CONT14
R. Haas, T. Hobiger, S. Kurihara, and T. Hara
Summary: Earth rotation results from the ultra-rapid operations during the continuous VLBI campaigns CONT11 and CONT14 are presented. The baseline Onsala-Tsukuba, i.e., using two out of the 13 and 17 stations contributing to CONT11 and CONT14, respectively, was used to derive UT1-UTC in ultra-rapid mode during the ongoing campaigns. The latency between a new observation and a new UT1-UTC result was less than 10 min for more than 95 % of the observations. The accuracy of the derived ultra-rapid UT1-UTC results is approximately a factor of three worse than results from optimized one-baseline sessions and/or complete analysis of large VLBI networks. This is, however, due to that the one-baseline picked from the CONT campaigns is not optimized for earth rotation determination. The results prove that the 24/7 operation mode planned for VGOS, the next-generation VLBI system, is possible already today. However, further improvements in data connectivity of stations and correlators as well in the automated analysis are necessary to realize the ambitious VGOS plans.

Terrestrial monitoring of a radio telescope reference point using comprehensive uncertainty budgeting – Investigations during CONT14
M. Lösler, R. Haas, and C. Eschelbach
Summary: During the 15-day-long global very long baseline interferometry campaign CONT14, a terrestrial monitoring campaign was carried out at the Onsala Space Observatory. The goal of these efforts was to monitor the reference point of the Onsala 20 m radio telescope during normal telescope operations. Parts of the local site network as well as a number of reflectors that were mounted on the 20 m radio telescope were observed in an automated and continual way using the in-house-developed software package HEIMDALL. The analysis of the observed data was performed using a new concept for a coordinate-based network
adjustment to allow the full adjustment process in a true Cartesian global reference frame. The Akaike Information Criterion was used to select the preferable functional model for the network adjustment. The comprehensive stochastic model of this network adjustment process considers over 25 parameters, and, to describe the persistence of the observations performed during the monitoring with a very high measurement frequency, includes also time-dependent covariances. In total 15 individual solutions for the radio telescope reference point were derived, based on monitoring observations during the normal operation of the radio telescope. Since the radio telescope was moving continually, the influence of timing errors was studied and considered in the adjustment process. Finally, recursive filter techniques were introduced to combine the 15 individual solutions. Accuracies at the sub-millimeter level could be achieved for the radio telescope reference point. Thus, the presented monitoring concept fulfills the requirement proposed by the global geodetic observing system (GGOS).

4 Technical R&D

4.1 Millimetre/sub-millimetre devices

[Module: national A7]

The Group for Advanced Receiver Development (GARD) at OSO carries out research and development work on mm and sub-mm technology that is further implemented into receivers and their components in order to maintain the observatory at the forefront of instrumentation. These technological developments are directly incorporated into the receivers that GARD builds for the Onsala 20 m telescope, APEX, and ALMA.

While not directly part of the National Facility activities, it is still worth mentioning two results from the graduate education in the academic part of GARD, of importance for radio astronomy at THz frequencies. Sasha Krause presented his Licentiate thesis “Ultra-thin Niobium Nitride Films for Hot Electron Bolometer and THz Applications” in February 2016, and Haval Rashid defended his PhD thesis “Towards Ultimate Performance of THz Heterodyne Receivers: SIS Frequency Multiplier and Wideband Passive Components” in April 2016.

4.2 LOFAR

[Modules: national A4, international A3]

LOFAR’s data processing infrastructure has been deployed on Chalmers Centre for Computational Science and Engineering (C3SE) compute cluster. This allows us to work with the large data volumes produced by the LOFAR telescope. The deployment has been commissioned using one of the 3000 planned observations from the LOFAR Survey, a project that will ultimately produce 50 Petabytes of data.

With this commissioned system, we can offer automated processing of LOFAR observations to the Swedish community. This is particularly useful now as the survey is ramping up its observation rate with well over 100 observation planned for the coming year. Astronomers in Sweden can avail of the C3SE deployment to mine this rich resource. An image produced by the system is shown in Figure 4.1.
**Figure 4.1.** A cut-out from a user's observation using LOFAR to observe the galaxy NGC3631. An area of 625 square degrees was imaged to allow the removal of strong contaminating sources from the field. The above image contains the inner 9 square degrees of the field. It is formed using the low to intermediate resolution components of the array to capture the extend structure of the galaxy of interest and provides a resolution (beam size) of 25 arcseconds. The observing frequency is centred at 145 MHz with a bandwidth of 35 MHz. The image was produced using the Prefactor pipeline.

Additionally, OSO maintains the survey progress web app which allows users to quickly search the sky using the standard Aladin astronomical tools and determine the LOFAR survey status of their object of interest. I.E. if is observed, processed or scheduled for observation. OSO also provides a "quick look" app to facilitate wide field analysis of LOFAR fields. Complete images are often too large to fit in the RAM of typical workstations. This service allows fast viewing of full field of view maps.

Software to facilitate the use of cross correlated data from single stations has been developed at OSO. This lowers the barrier to using the single station interferometric modes by providing Python modules to handle metadata generation, coordinate systems, geometric phase calibration. It also supports data output in the standard Measurement Set format making the data compatible with most commonly used interferometric software suites developed in the last decade.

OSO also provides software to produce interferometric products from LOFAR's Transient Buffer Boards (TBBs). LOFAR's TBBs allow the telescope to capture intense transient events for later detailed analysis. Using the tools developed at OSO one can correlate these TBB data and produce sky maps with extremely fine control over time and frequency resolution.
4.3 VLBI
[Module: international A3]

The e-VLBI mode at 2 Gbit/s (described in the 2015 activity report) was further tested and offered to the user community from the autumn of 2016. OSO was one of the first EVN station introducing the concept of disk-shipping-less model in 2016. This has worked very well. Turning to disk-less operations have many significant advantages. Stations, such as OSO, will not need to bother with conditioning, changing and shipping disk packs, and no recording media would need to be sent out before each session. Furthermore, transfers could be done practically automatically, and the results of significant sub-set of the EVN network will be available in real-time.

4.4 ALMA
[Module: national A3]

The Nordic ARC Node in Onsala has actively participated in all the Commissioning and Science Verification (CSV) observations with ALMA in VLBI mode (ALMA Phasing Project, APP). The PolConvert code (developed at the Node) has been updated and prepared for the Event Horizon Telescope (EHT) observations, planned for early April 2017. The ARC Node has also developed all the ALMA calibration scripts (QA2) for the APP observations, and is expected to participate in the calibration of the science observations. Investigations to adapt the PolConvert code (Marti-Vidal et al. 2016, A&A, 587, 143) for its use in wide-band VLBI observations with the EVN have also started.

4.5 Geoscience
[Module: national A2]

Receivers for the Onsala Twin Telescope (OTT) were developed during 2016, see Section 7 in this report. Smaller technical development projects for the geoscience activities are described in Section 5.6.

5 Instrument development and upgrades

5.1 The Onsala 20 m telescope
[Modules: national A2, A4 and A8, international A3]

The demand from astronomy and geodesy VLBI on wider bandwidth as well as the new receiver for the 3 and 4 mm band and the new 2 x 4 GHz FFTS installed in 2015 required an upgrade of the IF system of the 20 m telescope. The receivers used for EVN (X, K, Ka and V band) and IVS (S, X band) were using down-conversion scheme limited to either 512 MHz or 1 GHz. The IF system for single dish mode was limited to 1 GHz for the K, Ka and V bands. The signal transport from the telescope cabin to the control room was done using Radio Frequency Over Fiber (RFoF) link with highest frequency of 12 GHz. To be able to match the EVN and IVS requirements as well as to utilize the full capability of the newly installed equipment during 2016 we have made extended upgrade of the down convertors. After the upgrade, we are able to handle simultaneous bandwidth of 4 GHz for in two polarisations for all receivers in the cabin. For the 3 and 4 mm receivers, the upgrades we made allow to perform observations in two 4 GHz bands (two polarisations or two side-bands in one polarization), or four 2.5 GHz bands (both polarisations and sidebands covered). We have also installed a new RFoF link with
highest frequency of 18 GHz which will allow to make the data transport compatible with IVS frequency band and will make possible the direct digitalization of the RF signal. See Figure 5.1.

![Figure 5.1. IF down converter (left) and IF distribution and RFOF receiver in the control room (right).](image)

In the spring of 2016, the new 4 mm receiver (hosted in the same cryostat as the 3 mm) was extensively and successfully used in Science Verification projects and is since routinely offered in Call for proposals as one of our facility instruments. In the autumn, the upgrades discussed above – bandwidth as well as full polarisation/sideband IF coverage at 3 and 4 mm – were successfully commissioned on sky.

5.2 APEX: ALMA Band 9 receiver installed in SEPIA
[Modules: national A, international A]

In 2016, OSO’s Group for Advanced Receiver Development (GARD) performed four missions to APEX telescope, which included the de-installation/reinstallation of the new SEPIA receiver (Swedish-ESO PI Instrument for APEX) to a position at the telescope shared with other PI instruments. The SEPIA receiver is a completely new instrument that allows using up to three ALMA receiver cartridges. It consisted, at the start, of a cryostat and a pre-production ALMA Band 5 receiver cartridge that covers the frequency range 158–211 GHz, built under EC FP6 funded project, and upgraded by GARD. ESO contributed to SEPIA with hardware and commissioning. The Band 5 receiver is on big demand as a pathfinder for the ALMA Band 5 observations starting in 2018.

In February of 2016, an ALMA Band 9 receiver for the frequency band 600–722 GHz was installed into the SEPIA cartridge. The installation was a joint effort by teams from Nederlandse Onderzoekschool Voor Astronomie (NOVA) in the Netherlands and GARD. Science verification observations of the band 9 receiver on Swedish time took place in June and August (Figure 5.2), and the first regular observations on Swedish time were successfully carried out in August.
5.3 ALMA Band 5 full production project
[Module: national A7]

The ALMA Band 5 receiver covers the frequency range 163–211 GHz and is centered on the para-H$_2$O (3$_{13}$–2$_{20}$) line at 183 GHz; one of the few H$_2$O lines that can be observed from the Earth’s surface (at the high-altitude ALMA site under good weather conditions the atmospheric transmission can approach 50 % at the line peak). The ALMA Observatory Board decided in spring 2012 to finance the full deployment of Band 5 receivers on ALMA. In the full production project GARD collaborates with Nederlandse Onderzoekschool Voor Astronomie (NOVA) in the Netherlands, and with the National Radio Astronomy Observatory (NRAO) in the USA. A contract was signed in February 2013 to produce 67 Band 5 cartridges of a slightly modified design compared to those made for an earlier EU project (in which GARD produced Band 5 receiver cartridges). By the end of 2016, more than 37 Band 5 receiver cartridges have been delivered to the ALMA Project. The installed Band 5 receivers have passed scientific commissioning and the ALMA Band 5 receivers will be offered for observations during cycle 5 (2018).

5.4 LOFAR
[Modules: national A4, international A2]

During the end of 2016, the Onsala LOFAR station was upgraded significantly. The local control unit (LCU, or main control computer) was upgraded to a computer with substantially better performance and disk space, and it also now uses a more modern operating system. These technical improvements allowed the station to run more sophisticated operational modes and more local data recording volume. This will help the LOCAL and ILT LOFAR users considerably with their operations.

In addition, in 2016 the LOFAR environment monitoring software iStnMonitor, developed in-house by OSO, was enhanced such that it could be connected to the OSO observatory monitoring and control system. Thus it is now possible to monitor the Swedish LOFAR station’s health and status centrally alongside the other infrastructures under OSO operations. This allows uniformity, redundancy, shorter down-times and is thus an improvement also for the LOFAR project.
5.5 VLBI
[Module: international A3]

The commissioning of a complete new parallel VLBI system was completed in 2015. We are now able to observe routinely in VLBI-mode with both the 20 m and the 25 m telescope simultaneously. In addition, the so called FlexBuff, allowing a disk-shipping-less operation (see Section 4.3), was taken into operation. No major upgrades were done during 2016.

5.6 Geoscience
[Module: national A3]

5.6.1 Aeronomy station
The LO chain of the 110–116 GHz CO/O₃ radiometer has been updated. A small and programmable frequency synthesizer has been implemented in the system. This makes it easy to automatically retune the LO frequency and makes the radiometer very compact and moveable (Figure 5.3).

Figure 5.3. The compact 110–116 GHz CO/O₃ radiometer. The quadratic box in the middle is the new synthesizer. Except for a 10 MHz reference frequency only a spectrometer is needed to use the system.
5.6.2 Gravimeter laboratory
A seismographic data acquisition system (Earthworm 7.8) and miniseed server was installed in 2016. Its purpose is to supply 100 samples per second data streams taken from the superconducting gravimeter ahead of the low-pass filter in the 1 samples per second standard data path. The system still awaits a step of completion. When the appropriate signal tap is configured the high-frequency channel will serve microseismic noise reduction in absolute gravity campaigns, avoiding the low-pass filter's signal distortion. As for bragging, the measure will furnish an extreme broadband instrument capable to measure variations of vertical acceleration with periods from tens of milliseconds to a few cycles in the lifetime of the station; and, in combination with absolute gravity, secular change on the order of 0.2 nm/s² per year.

5.6.3 A laser-based sensor system for sea level monitoring
A laser-based sensor system was developed within a Bachelor’s thesis project during the spring semester of 2016. It has been installed in the super-tide gauge in order to provide an independent assessment of the official sensors, the bubblers and the radar. The radar data are publically available for download via SMHI’s web page. The laser sensor is less reliable in terms of a continuous data flow, but the indications are that when data are acquired, their accuracy is superior to the other sensors. A careful assessment will be made when a time series of simultaneous observations from the three different types of sensors are available over a time period of the order of 1–2 years.

6 SKA design activities

During 2016, 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 built in two phases with phase 1 (SKA1) planned to be fully operational in 2023 and phase 2 likely to be built in the 2030’s at the earliest. In June 2013 contracts were awarded to 11 multi-national design consortia that (managed by the central SKA Office) will accomplish the final detailed engineering design of SKA Phase 1. Sweden, represented by OSO, is part of two such design consortia, the Dish and the Wide Band Single Pixel Feed consortia (SKA-DC and SKA-WBSPF).

6.1 Band 1 in SKA-DC

OSO is work package (WP) leader for the Band 1 Single Pixel Feed (SPF) WP within SKA-DC. Within this WP, OSO has the overall responsibility to design, prototype and characterize a feed and low-noise receiver package that covers 350–1050 MHz frequency range. According to the SKAO prioritization, this receiver band will be one of the first implemented on the SKA together with Bands 2 and 5. Partners in this WP are Leax Arkivator, a Gothenburg based company, providing expertise in antenna manufacturing, the National Research Council (NRC) of Canada, providing state of the art low-noise amplifiers (LNAs), Omnisys Instruments AB (Sweden), working on the design of the control system and the final design for mass production, and Low Noise Factory (Sweden), providing on-shelf world-class LNAs. According to the time line, the detailed design during should be completed during 2016, and a qualification model of the system should be constructed during 2017. The last phase of the project is the test of the prototype on an SKA dish on the SKA site in the Karoo desert in the late 2017.

At the beginning of the project, the design of the Band 1 system had a feed at room temperature and LNAs mounted inside a cryostat. The development of extremely low noise
transistors for ambient temperatures done at Department of Microtechnology and Nano Science (MC2) at Chalmers resulted in a commercial Low Noise Amplifier manufactured by Low Noise Factory. This amplifier made world record in delivering equivalent noise temperature of 10 K at ambient room temperature. This performance was estimated to be comparable to the equivalent noise of an LNA installed at cryogenic temperature and the additional noise contribution from the cables at ambient temperature used to connect the cryostat to the feed. The Band 1 design team suggested to the work package leader and the SKA Organisation to change the design concept from a cryogenic system to an ambient temperature system, which was approved. This will allow maintaining the Band 1 specification with a system that is much simpler, and to save energy since the system will not require a cryogenic compressor.

To perform complete tests of the Band 1 ambient temperature prototype we made agreement with the National Observatory of Canada (NOC) to perform tests on the DVA-1 dish in Penticton. The feed was delivered and on site in May 2016. Dominion Radio Astrophysical Observatory (DRAO) staff, together with Magnus Dahlgren and Jonas Flygare from OSO, performed the test (Figure 6.1). Measurements with the Band 1 receiver on DVA1 included several tipping curves swept over elevation for different azimuth directions. This was done for preferable frequencies, relatively free from RFI. Several beam patterns were also extracted from sweeping across the sun. See Figure 6.2. A new measurement campaign is planned for May 2017.

Figure 6.1. Jonas Flygare and Magnus Dahlgren from OSO in front of the Band 1 receiver installed in the Sky Measurement facility in Penticton, Canada.
During the second half of 2016, the design team worked together with Leax Arkivator on detailed design of the qualification model of the Band 1 feed. Considerable changes in the control electronics were made because of the switch from cryogenic to ambient temperature system.

In November 2016, a Detailed Design Review for the SKA-mid Band 1 and Band 2 was held. An independent review panel provided the feedback that the Band 1 team needs some more effort in order to get their final approval to build the qualification model. The work on that continues in early 2017 with the goal to minimise the schedule impact.

6.2 SKA-WBSPF

OSO leads the Wideband Single Pixel Feed Advanced Instrumentation Program (WBSPF) consortium that is part of the Advanced Instrumentation Program (AIP) for SKA. The AIP is intended to develop technology that would be employed as a second-generation SKA-1 receiver or on SKA Phase 2. The scope of work for the WBSPF includes developing a broad spectrum single-pixel-feed, LNAs, and digitizers. Specifically, WBSPF seeks to greatly expand the frequency range covered by present radio astronomy receiver systems, typically about a factor of two in frequency, to frequency ranges of factors of 4 to 8. As consortium leader, OSO has the overall management and coordination responsibility to deliver the work according to the time plan and specification. In addition, OSO provides system engineering for the consortium.
The yearly consortium meeting for the WBSPF took place in April 2016 and was hosted by Joint Laboratory for Radio Astronomy Technology (JLRAT) in China. Part of the meeting was allocated for the Concept Design Review (CoDR) of the WBPSF. The review panel acknowledged that the WBSPF design consortium led by the OSO WBSPF team has achieved the goals of the CoDR and is on the right track moving towards preliminary design of Wide-Band receiver for SKA.

During the autumn of 2016 we worked on finalizing the first prototypes of the sub-elements – feeds and LNAs for the Band B of WBSPF. Beam tests were performed at Yebes Observatory in Spain, and the tests results are very satisfactory. The current Band B feed design meets the efficiency specifications. We have also done an analysis of the expected sensitivity performance. The Band B feed and LNA meets the 6.1 m²/K specification up to 10 GHz, and the 4.7 m²/K up to 15.5 GHz. Above 20 GHz, the sensitivity of the Band B feed is below the specification of 3.5 m²/K.

For the Band B Low Noise Amplifiers, OSO worked closely with Low Noise Factory on the specification of amplifier. Tests during the autumn of 2016 showed very good equivalent noise temperature and flat gain of about 30 dB over the band.

7 OTT: Twin-telescope system for geodetic VLBI at Onsala

The decision about funding the Onsala Twin Telescopes (OTT) was made by Knut and Alice Wallenberg (KAW) foundation in April 2012. Obtaining permission from the authorities to build the telescopes required a special process because of the closeness to the sea. The necessary permits were obtained in February 2014 and by the end of that year the procurement order for the telescopes were signed. The telescopes are parabolic dishes with a diameter of 13.2 m equipped with an axis-symmetric ring focus subreflector systems with a diameter of 1.55 m. The construction of the telescope foundations was described in the activity report for 2015. It was handled separately by Chalmersfastigheter AB and via the main contractor Hansson & Söner. The foundations were ready for the telescopes in February 2016.

The containers with all the telescope parts arrived in June 2016 and the installation by the German company MT Mechatronics started immediately thereafter and continued throughout the autumn. The Site Acceptance Test took place in December 2016. The two telescopes are pictured in Figure 7.1.

Figure 7.1. The Onsala Twin Telescopes on 2 January 2017.
Two broad-band VGOS (VLBI Geodetic Observing System) receivers were designed and built in-house, assembled and tested, during 2016. The cryogenic receivers integrate the broad-band feeds and the first stage amplifiers at cryogenic temperature to provide ultimate sensitivity. The receiver design was driven by two requirements:

1. to fit into the feed cone on the telescopes and
2. to make the interior and the volume dedicated for the feed installation to have a sufficient flexibility in order to allow installation of different types of feeds.

We selected two different types of feeds: one Quadruple-Ridge Feed Horn (QRFH) and one Eleven feed. Figure 7.2 depicts the two different feeds mounted on their respective receiver and Figure 7.3 depicts the installation of the QRFH receiver in the telescope. Measurements in the laboratory resulted in bandwidths of 3.0–15.2 GHz and 2.2–14.0 GHz for the QRFH and the Eleven feed receiver, respectively, when the appropriate filters had been installed for adaption to the back-end electronics.

Figure 7.2. The two broad-band receivers in the electronics laboratory during the assembling phase in August 2016. To the left the receiver with the QRFH feed and to the right the identical receiver but with the Chalmers in-house developed Eleven feed.
8 Computers and networks
[Module: national A10]

Presently there are at OSO a cluster of four machines (48 cores) together with 100 TB of data storage. In 2016, a larger OSO owned cluster was installed at the SNIC–C3SE node at Chalmers and consists of 5 machines with a total of 100 cores, additionally 2 machines each have 2 GPUs. The cluster has 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.

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). When the SUNET 100 Gbit/s backbone network was rolled out in 2016, OSO was connected to that network by installing 100 GE equipment at Onsala. OSO is now 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 correlators.

9 Frequency protection
[Module: national A9]

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 Bonn, Germany. CRAF (in principle through its Frequency Manager) attends a number of international meetings where a possible threat to radio astronomy is at stake. As of 2016, CRAF has broadened its leader/coordinator activities to prepare for the 2019 ITU World Radiocommunication Conference. The OSO CRAF member focus mainly on interference issues at local and national levels (via Post- och telestyrelsen). Examples of issues during 2016 concerned the 2.3 GHz band and the LOFAR station registration at ITU.

10 Memberships of international committees

During 2016, OSO was involved in the following international boards and coordinating committees. The observatory director serves on many of these boards.

- The European VLBI Network (EVN) for astronomical VLBI (the Director is a board member, and Michael Lindqvist is chairman of the Programme Committee and a member of the Technical Operations Group (TOG))
- 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)
- 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)
- International VLBI Service for Geodesy and Astrometry (IVS), which operates geodetic VLBI (Rüdiger Haas is board member)
- International Earth Rotation and Reference Frame Service (IERS) (Rüdiger Haas is 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)

11 EU projects

The third EU-funded RadioNet project (Advanced Radio Astronomy in Europe) finished at the end of 2015. During 2016, OSO took part in the preparation of three successful Horizon 2020 projects (proposals submitted in March 2016) starting in late 2016 or early 2017: RadioNet, AENEAS and Jumping JIVE.
**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 will be part of the Transnational Access (TA) program via APEX and the EVN, participate in the Networking Activities. In addition, and will play a major role in all of the Joint Research Activities which includes both software and hardware development.

**AENEAS**
The large scale, rate, and complexity of the data that the Square Kilometre Array (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.

**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 Very Long Baseline Interferometry (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 radioastronomical 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.

**12 Workshops, schools, etc.**
ALMA proposal preparation workshops were organized by the Nordic ARC Node in Onsala, see Section 1.2.

**13 Education**
The OSO staff does 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 national facility does however support teaching by making a small fraction of the time on the 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. Additionally, students from the universities in Stockholm and Lund visited the Observatory to carry out observations and/or to learn about radio astronomy.
14 Outreach
[Module: national A6]

During the year 1900 people visited Onsala Space Observatory, its telescopes and exhibition. Most came as part of a total of 65 guided tours, of which school groups of all ages accounted for 25 of the tours. Many 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 a special event for the observatory’s closest neighbours in the village of Råö.

Our SALSA radio telescopes were booked for an average of 21 hours per week, on average 3.5 h per booking, by students, teachers and amateur astronomers from ten countries. This includes Sweden but also from as far away as the US, Israel and Ecuador. 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. News reports from Sweden and around the world featured the Band 1 feed for SKA, the precessing black hole jet in galaxy NGC 1377, a tidal disruption event observed by the EVN, and ALMA observations of disk winds from a young star, and a forming triple-star system. Onsala Space Observatory was the focus of a programme on Swedish national public radio (Vetandets värld) about radio astronomy and China’s FAST telescope. 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 October, at events in Gothenburg, Växjö, Trollhättan, Stenungsund and Fjärås.

Two MOOCs (massive open online courses) titled Sensing Planet Earth were given by OSO’s host department at Chalmers, Earth and Space Sciences. They included geoscience methods used at OSO, e.g., geodesy VLBI and tide gauges for sea level measurements, and were a great success. The two courses, From Core to Outer Space and Water and Ice, each attracted over 3000 students from 129 countries, most from the US, India and Sweden, and achieved the highest completion rates yet for Chalmers MOOCs.

15 Changes in organisation
[Module: national A1]

The Steering Committee, chaired by Kjell Möller, continued its work during 2016 with no changes in membership.

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). In the spring, TAC member Erik Zackrisson (Uppsala University) was replaced with Sebastien Muller (Chalmers), and in the autumn Magnus Thomasson (Chalmers) was replaced with Sofia Ramstedt (Uppsala University).

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.
16 Importance to society

OSO 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.

17 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, Omnisys Instruments AB and Low Noise Factory) within the SKA-DC design consortium (see Section 6). Similar technology has possible commercial applications for geodetic and astronomical VLBI.
# Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>A&amp;A</td>
<td>Astronomy &amp; Astrophysics (a scientific journal)</td>
</tr>
<tr>
<td>AENEAS</td>
<td>Advanced European Network of E-infrastructures for Astronomy with the SKA</td>
</tr>
<tr>
<td>AGB</td>
<td>Asymptotic Giant Branch (AGB stars are giant evolved stars)</td>
</tr>
<tr>
<td>AGN</td>
<td>Active Galactic Nucleus</td>
</tr>
<tr>
<td>AIP</td>
<td>Advanced Instrumentation Programme (SKA)</td>
</tr>
<tr>
<td>ALMA</td>
<td>Atacama Large Millimeter/submillimeter Array (Chile)</td>
</tr>
<tr>
<td>APEX</td>
<td>Atacama Pathfinder Experiment (Chile)</td>
</tr>
<tr>
<td>APP</td>
<td>ALMA Phasing Project</td>
</tr>
<tr>
<td>ARC</td>
<td>ALMA Regional Centre</td>
</tr>
<tr>
<td>ASTRON</td>
<td>Netherlands Institute for Radio Astronomy</td>
</tr>
<tr>
<td>AU</td>
<td>Astronomical Unit (the distance between the Sun and Earth)</td>
</tr>
<tr>
<td>C3SE</td>
<td>Chalmers Centre for Computational Science and Engineering</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide (molecule frequently observed by radio telescopes)</td>
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<tr>
<td>CoDR</td>
<td>Concept Design Review</td>
</tr>
<tr>
<td>Co-I</td>
<td>Co-investigator</td>
</tr>
<tr>
<td>CRAF</td>
<td>Committee on Radio Astronomy Frequencies (ESF)</td>
</tr>
<tr>
<td>DBBC</td>
<td>Digital Base Band Converter (equipment for VLBI observations)</td>
</tr>
<tr>
<td>DORIS</td>
<td>Doppler orbitography and radio-positioning integrated by satellite</td>
</tr>
<tr>
<td>DRAO</td>
<td>Dominion Radio Astrophysical Observatory</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
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<tr>
<td>EHT</td>
<td>Event Horizon Telescope</td>
</tr>
<tr>
<td>ERIC</td>
<td>European Research Infrastructure Consortium</td>
</tr>
<tr>
<td>ESDC</td>
<td>European Science and Data Centre (SKA)</td>
</tr>
<tr>
<td>ESF</td>
<td>European Science Foundation</td>
</tr>
<tr>
<td>ESO</td>
<td>European Southern Observatory</td>
</tr>
<tr>
<td>EUREF</td>
<td>IAG Reference Frame Sub-Commission for Europe</td>
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<tr>
<td>e-VLBI</td>
<td>electronic VLBI (fibre optics connect radio telescopes to a central data processor, which correlates the data from the telescopes in real-time)</td>
</tr>
<tr>
<td>EVGA</td>
<td>The European VLBI Group for Geodesy and Astrometry</td>
</tr>
<tr>
<td>EVN</td>
<td>European VLBI Network</td>
</tr>
<tr>
<td>FFTS</td>
<td>Fast Fourier Transform Spectrometer</td>
</tr>
<tr>
<td>FP6</td>
<td>The Sixth Framework Programme for Research and Technological Development (EC)</td>
</tr>
<tr>
<td>GARD</td>
<td>Group for Advanced Receiver Development (part of OSO)</td>
</tr>
<tr>
<td>GMVA</td>
<td>Global Millimeter VLBI Array</td>
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<tr>
<td>GNSS</td>
<td>Global Navigational Satellite Systems</td>
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<tr>
<td>GNSS-R</td>
<td>GNSS reflectometry</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GPU</td>
<td>Graphics Processor Unit</td>
</tr>
<tr>
<td>GSAC</td>
<td>Galileo Scientific Advisory Committee of the European Space Agency</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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<tr>
<td>SMHI</td>
<td>Sveriges meteorologiska och hydrologiska institut (Swedish Meteorological and Hydrological Institute)</td>
</tr>
<tr>
<td>SNIC</td>
<td>Swedish National Infrastructure for Computing</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal-to-Noise Ratio</td>
</tr>
<tr>
<td>SNSN</td>
<td>Svenska nationella seismiska nätverket</td>
</tr>
<tr>
<td>SP</td>
<td>Technical Research Institute of Sweden (now part of RISE)</td>
</tr>
<tr>
<td>SPF</td>
<td>Single Pixel Feed</td>
</tr>
<tr>
<td>SUNET</td>
<td>Swedish University Computer Network</td>
</tr>
<tr>
<td>SWEPOS</td>
<td>The Swedish permanent GNSS network, hosted by Lantmäteriet</td>
</tr>
<tr>
<td>TAC</td>
<td>Time Allocation Committee</td>
</tr>
<tr>
<td>TBB</td>
<td>Transient Buffer Boards (for LOFAR)</td>
</tr>
<tr>
<td>UT1</td>
<td>The principal form of Universal Time (which is based on Earth’s rotation)</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time (an atomic timescale that approximates UT1)</td>
</tr>
<tr>
<td>VGOS</td>
<td>VLBI Geodetic Observing System</td>
</tr>
<tr>
<td>VLBI</td>
<td>Very Long Baseline Interferometry</td>
</tr>
<tr>
<td>VR</td>
<td>Vetenskapsrådet, The Swedish Research Council</td>
</tr>
<tr>
<td>WBSPF</td>
<td>Wideband Single Pixel Feeds</td>
</tr>
<tr>
<td>WDS</td>
<td>World Data System, an Interdisciplinary Body of the International Council for Science (ICSU)</td>
</tr>
<tr>
<td>WP</td>
<td>Work Package</td>
</tr>
</tbody>
</table>
Publications 2016

This document lists publications in refereed journals 2016 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, projects with Nordic ARC node involvement (20/19) *(total/Swedish)*
• **APEX** observations (all APEX partners’ observing time) (79/10)
• **Astronomical VLBI** observations with EVN and GMVA, or using JIVE (29/6)
• **LOFAR** observations (37/13)
• **Geoscience** instruments (21/8)
• **Onsala 20 m telescope, single-dish** observations (5/4)

In addition to the publications listed below, in 2016 there were two publications using astronomical data from the satellite *Odin* (now operating mainly in aeronomy mode), eight publications using data from *SEST* (closed in 2003), and eleven publications by OSO staff on radio astronomical instrumentation, methods and techniques.

Note:
- The publications are separated in two groups: with or without a Swedish author
- In each section, the references are sorted by first author.

**ALMA, publications, in refereed journals, with Nordic ARC node involvement 2016**

**Swedish authors (ALMA – ARC node)**


**International authors (ALMA – ARC node)**


**APEX, publications in refereed journals 2016**

**Note:** This list is based on APEX publications in the ESO Telescope Bibliography “Telbib”, http://telbib.eso.org/.

**Swedish authors (APEX)**


Dense gas in the Galactic central molecular zone is warm and heated by turbulence. Ginsburg, Adam; Henkel, Christian; Ao, Yiping; Riquelme, Denise; Kauffmann, Jens; Pillai, Thushara; Mills, Elisabeth A. C.; Requena-Torres, Miguel A.; Immer, Katharina; Testi, Leonardo; Ott, Juergen; Bally, John; Battersby, Cara; Darling, Jeremy; Aalto, Susanne; Stanke, Thomas; Kendrew, Sarah; Kruijssen, J. M. Diederik; Longmore, Steven; Dale, James; Guesten, Rolf; Menten, Karl M. A&A, vol. 586, p. A50- (2016)


International authors (APEX)


Properties of massive star-forming clumps with infall motions. He, Yu-Xin; Zhou, Jian-Jun; Esimbek, Jarken; Ji, Wei-Guang; Wu, Gang; Tang, Xin-Di; Komesh, Toktarkhan; Yuan, Ye; Li, Da-Lei; Baan, W. A. MNRAS, vol. 461, p. 2288-2308 (2016)


Deuteration in infrared dark clouds. Lackington, Matias; Fuller, Gary A.; Pineda, Jaime E.; Garay, Guido; Peretto, Nicolas; Traficante, Alessio. MNRAS, 2016, vol. 455, p. 806-819


Cloud Structure of Galactic OB Cluster-forming Regions from Combining Ground- and Space-based Bolometric Observations. Lin, Yuxin; Liu, Haoyu Baobab; Li, Di; Zhang, Zhi-Yu; Ginsburg, Adam; Pineda, Jaime E.; Qian, Lei; Galván-Madrid, Roberto; McLeod, Anna Faye; Rosolowsky, Erik; Dale, James E.; Immer, Katharina; Koch, Eric; Longmore, Steve; Walker, Daniel; Testi, Leonardo. ApJ, vol. 828, p. 32-


Observations of 6.7 GHz methanol masers with East-Asian VLBI Network. II. Internal proper motion measurement in G006.79-00.25. Sugiyama, Koichiro; Fujisawa, Kenta; Hachisuka, Kazuya; Yonekura, Yoshinori; Motogi, Kazuhito; Sawada-Satoh, Satoko; Matsumoto, Naoko; Hirano, Daiki; Hayashi, Kyosuke; Kobayashi, Hideyuki; Kawaguchi, Noriyuki; Shibata, Katsunori M.; Honma, Mareki; Hirota, Tomoya; Murata, Yasuhiro; Doi, Akihiro; Ogawa, Hideo; Kimura, Kimihiro; Niinuma, Kotaro; Chen, Xi; Xia, Bo; Li, Bin; Sorai, Kazuo; Momose, Munetake; Saito, Yu; Takaba, Hiroshi; Omodaka, Toshihiro; Kim, Kee-Tae; Shen, Zhiqiang. PASJ, vol. 68, p. 72- (2016)


Dense-gas properties in Arp 220 revealed by isotopologue lines. Wang, Junzhi; Zhang, Zhi-Yu; Zhang, Jiangshui; Shi, Yong; Fang, Min. MNRAS, vol. 455, p. 3986-3990 (2016)


Molecular Lines of 13 Galactic Infrared Bubble Regions. Yan, Qing-zeng; Xu, Ye; Zhang, Bo; Lu, Deng-rong; Chen, Xi; Tang, Zheng-hong. AJ, vol. 152, p. 117 (2016)


Astronomical VLBI, publications in refereed journals 2016

Note: This list is partly based on EVN Biennial reports 2011-2012 and 2013-2014 (http://www.evlbi.org/publications/publications.html) and information on the GMVA web site (http://www3.mpifr-bonn.mpg.de/div/vlbi/globalmm/)

Swedish authors (Astro VLBI)


International authors (Astro VLBI)


LOFAR, publications in refereed journals 2016

Note: This list is based on the publication list on the LOFAR web site: http://astron.nl/radio-observatory/lofar-science/lofar-papers/lofar/papers

Swedish authors (LOFAR)


LOFAR VLBI studies at 55 MHz of 4C 43.15, a \( z = 2.4 \) radio galaxy. Morabito L. K., Deller A. T., Rottgering H. et al., MNRAS, 461, 2676 (2016)


International authors (LOFAR)


Geoscience, publications, in refereed journals, using the infrastructure at the Onsala site, 2016

Swedish authors (Geoscience)


International authors (Geoscience)


Onsala 20 m telescope, single-dish observations, publications in refereed journals 2016

Swedish authors (OSO 20 m)


International authors (OSO 20 m)