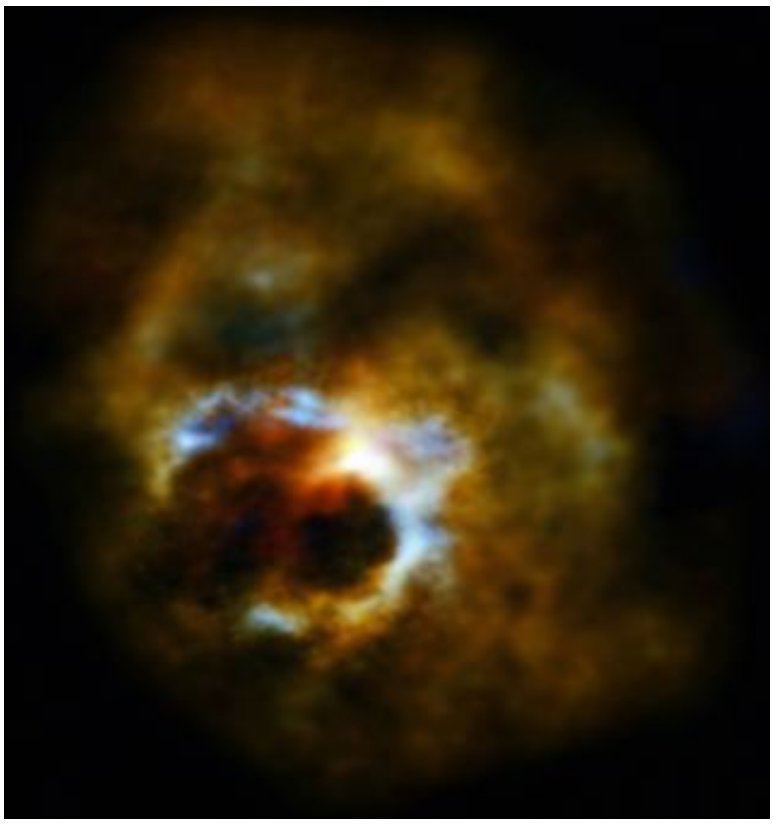
**ONSALA RYMDOBSERVATORIUM**
CHALMERS TEKNISKA HÖGSKOLA

**ONSALA SPACE OBSERVATORY**
CHALMERS UNIVERSITY OF TECHNOLOGY

Dnr: RoG 2015-0007-4.7

# Report on the activities in 2014 of Onsala Space Observatory The Swedish National Facility for Radio Astronomy

This report presents the activities at Onsala Space Observatory (OSO) during 2014; including the usage of the instruments for scientific purposes, according to the contract for operation of OSO between the Swedish Research Council (VR) and Chalmers.



***Cover figure***. *The heart of the binary star system Mira Ceti (Ramstedt et al. A&A 570, L14, 2014). The figure shows an ALMA + APEX CO(J=3-2) image, processed at the Nordic ARC node at Onsala, of the circumstellar gas around the red giant star Mira Ceti A and its white dwarf companion. Different colours correspond to different Doppler velocities (see Sect 5.5 and http://www.eso.org/public/images/potw1447a for more details).*

Onsala, 3rd March 2015

John Conway
Director, Onsala Space Observatory

# Contents

This report is divided into the following sections:


– 1. Operations
– 2. Quantitative measures of reliability
– 3. User statistics
– 4. Peer-reviewed papers
– 5. Selected scientific highlights
– 6. Technical R&D
– 7. Instrument development and upgrades
– 8. SKA design activities
– 9. Twin-telescope system for geodetic VLBI at Onsala
– 10. Replacement of Onsala 20 m telescope radome
– 11. Membership of international committees
– 12. RadioNet3 EU project
– 13. Workshop, schools, etc.
– 14. Education
– 15. Outreach
– 16. Changes in organisation
– 17. Importance to society
– 18. Importance to industry
– 19. Financial account

– Acronyms


## 1 Operations

During 2014 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 and astronomical VLBI

- The Nordic ARC node (the Atacama Large Millimeter/sub-millimeter Array Regional Centre node for the Nordic, and Baltic, countries)

- The Onsala aeronomy station for observations of atmospheric $H_2O$, CO, and $O_3$,
- Two water vapour radiometers (WVRs) to support space geodesy
- The Onsala gravimeter laboratory for absolute and relative gravimetry
- The tide gauges at Onsala
- The Onsala GNSS stations
- 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), respectively.

## 1.1 Telescopes

In general, all telescopes have operated according to the 2014 activity plan without any major problems, more details are given below;

- **Onsala 20 m telescope:** The Onsala 20 m telescope has operated according to the 2014 activity plan without any major problems during the year. A major event during the year was the replacement of the 40 year old radome during August and September (see Sect 10); an essential renovation which extends the operational life of the telescope for decades to come. On the instrumentation side the telescope was enhanced by the installation of a new 3 mm receiver and a new wideband FFTS backend as described in Sects 7.1 and 7.2.

- **Onsala 25 m telescope:** The Onsala 25 m telescope has operated according to the 2014 activity plan without any major problems during the year. Fifty years after its inauguration, on November 26, 1964, the telescope continues to produce frontline science being part of the EVN. In 1968 the telescope was involved in the first tape-recording enabled transatlantic VLBI observation. The telescope was used to discover the CH radical in interstellar space in 1973, and was involved in the first real time e-VLBI experiments in 2004.

- **APEX:** The Swedish APEX observations in 2014, in total 53 days, went smoothly. Both the instrument performance and the weather made it possible to carry out observations during the year with very high efficiency. To perform service mode observations OSO had observers on-site for about 176 man-days (counting only observing and on-site preparations not travel). The APEX data sets are now routinely transferred to the ESO archive within a few days of the actual observations and the PI then gets notified.

  During the Altiplanic winter shutdown period (Jan. – March), the SHFI receiver was equipped with new IF amplifiers to improve the IF system behaviour. Early in the year an agreement was reached with the ArTeMiS instrument team (an ESO PI 350 μm bolometer camera replacing Saboca) for access to Swedish PIs in exchange for the ArTeMiS team to be given access to about 50 hrs of observing time via their own proposals submitted to the Swedish TAC. In Nov. and Dec. 2014, the 64-pixel 345 GHz heterodyne camera SuperCam was installed in the Cassegrain cabin at APEX and was used on both Swedish and ESO time. The camera remains at the telescope site and is planned to be used again in April and May 2015 (with an improved efficiency after parts of the optical system are replaced).

  A “Science with APEX” meeting was organized at Ringberg outside Munich in January 2014. During the associated APEX Board meeting, the agreement for continuing APEX operations until the end of 2017 was signed by all three partners.

- **LOFAR:** The Swedish LOFAR station participated seamlessly within the International LOFAR Telescope (ILT) network. The time not dedicated to the ILT (nominally at least 10 %) was used in a multitude of ways.

– **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: 42 days of single-dish astronomy
21 days of astronomical VLBI
39 days of geodetic VLBI
– The Onsala 25 m telescope: 67 days of astronomical VLBI
– The LOFAR station has been operational throughout the year
– APEX telescope 45 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 27 and 10 days on the 20 m and 25 m telescopes respectively. There were a number of upgrades to the 20 m telescope in 2014 (e.g., new 3 mm receiver, new spectrometer, new beam-switch, new radome), in addition to normal maintenance activities (pointing etc.), which reduced the amount of time available for scientific observations. The time for geodetic VLBI includes 39 regular IVS-sessions in the R1-, RD-, RDV-, T2- and EUR-series plus the CONT14 campaign.

## 1.2 Nordic ARC Node

In 2014, the Nordic ARC provided support to the Nordic and Baltic ALMA communities for data reduction and analysis of ALMA data from all observing cycles. As there was no call for proposals this year, no proposal preparation workshops were organized. Data reduction for five Cycle 0, 1, and 2 ALMA proposals (with Nordic PIs or co-Is) by ARC node visitors was supported by Nordic ARC staff. Furthermore, four additional projects were supported for local PI/co-I. With the increase in data volume, each project has taken an average of two weeks full time support and so far 90 % of all Nordic projects have benefited from Nordic ARC face-to-face support. Additionally, the Nordic ARC provided contact scientists for each project. 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.

The Nordic ARC performed quality assessment on more than 50 European ALMA Scheduling Blocks (SB) with most scheduled projects consisting of more than one SB). The majority of these processed SBs were for Nordic projects. In total fraction this means that the Nordic ARC performed quality assessment for approximately one quarter of all European delivered data sets.

In May, the ARC node organized the annual face-to-face meeting of the European ARC node representatives, where the development of the ARC node network was discussed. This discussion was taken as input for an international review of the ARC node network in Jan. 2015. In August, the Nordic ARC staff organized a seven day PhD school at the DARK institute in Copenhagen.

The ARC node continued their development of advanced data analysis tools. These tools are published at the Nordic ARC webpage (www.nordic-alma.se). This year saw the release of

the uv-fitting code UVMULTIFIT, and the uv-stacking code STACKER. A member of the node staff also further refined the scripts he wrote and designed, which are being used by ALMA to package the data for delivery to the PIs.

In support of their duties Nordic ARC node staff travelled to ESO to learn the ALMA pipeline process. In October the ARC node staff attended the annual ARC node network all-hands meeting near Grenoble. The ARC manager also presented the plenary talk about ALMA and the ARC nodes at the Spanish Astronomical Society meeting in Sep. Finally, an ARC member of staff gave several presentations about his developments for phasing up the ALMA antennas and the software tools developed within the node at a number of technical workshops and meetings in Australia, Italy, and Canada.

## 1.3 Geophysical Instruments

The geodetic VLBI days include regular IVS-sessions in the R1-, RD-, RDV-, T2- and EUR-series, and the CONT14 continuous-VLBI campaign. Eleven of the 50 initially planned geodetic VLBI sessions could not be observed due to the radome replacement. Several sessions were recorded in parallel with the old Mark4/Mark5A recording and the new DBBC/Mark5B+ systems, including the complete CONT14 campaign, and the derived results were compared. Since the comparisons verified that the results are comparable, the Mark4 rack was removed in Aug. and since then the DBBC/Mark5B+ system is used for production. The complete CONT14 was operated as ultra-rapid UT1-UTC session, i.e., all data were real-time transferred to the VLBI correlator at GSI in Tsukuba (Japan), where they were correlated and analysed in near real time by our Japanese colleagues.

For the other geophysical facilities the activities can be summarised as follows:

- **Aeronomy station:** The aeronomy station performed continuous observations of mesospheric CO, $O_3$, and $H_2O$ (except for maintenance periods). Mesospheric $H_2O$ profiles from 2013 were delivered to the Network for the Detection of Atmospheric Composition Change (NDACC). The first combined CO and $O_3$ data from the double-side-band 3 mm frontend is now processed and will be compared to satellite data.

- **Water Vapour Radiometers:** The two water vapour radiometers Astrid and Konrad measure the amount of water vapour in the atmosphere. Astrid was operating continuously during the year, although was suffering from a failure of the 31 GHz channel until Sep. 2014, during this period its data until then are only useful during atmospheric conditions with no significant amount of liquid water. Konrad was operating continuously during the first six months of 2014. During the second half of the year Konrad has had a broken mechanical waveguide switch needed for calibrations.

- **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. 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. Since January 2012 the system delivers one-second data online with two minutes latency at maximum. See http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html. The records are submitted to the archive of the Global Geodynamics Project (GGP) at GeoForschungsZentrum (GFZ) Potsdam (Germany), on a monthly routine.

- **Tide gauges:** The GNSS-based tide gauge was operated throughout the year. Data of both GPS and GLONASS were received and analysed with different analysis strategies. The results formed the basis for an assessment of multi-GNSS reflectometry. In August, a collaboration with the GFZ was initiated and other GNSS-R equipment developed by GFZ was placed next to the Onsala GNSS-R tide gauge. In the autumn work started to build a third GNSS-R sensor for sea-level monitoring and focusses on GLONASS signals. In the spring, a student team of the University of Applied Sciences in Hannover (Germany) visited the observatory and carried out a survey of the tide gauge instrumentation. During this visit the precise height relations between the various geodetic monuments were determined. A new tide gauge station developed together with SMHI, to become one site in the Swedish tide gauge network when ready for operation, started test observations in November.

- **GNSS stations:** OSO's primary GNSS station is also a part of the SWEPOS network operated by Lantmäteriet. Additionally, it is one of the fundamental reference sites used in the global IGS network, as well as in the European EUREF network. In the autumn a dense network of GNSS stations was established around the building site for the Onsala Twin Telescope. Equipment (masts, antennas, receivers) for four sites were provided by Lantmäteriet. Two further sites will be equipped at a later stage.

- **Seismometer station:** OSO hosts a seismograph station of the "Svenska nationella seismiska nätverket" (SNSN) at Uppsala University. We have data access to the local seismometer and keep a continuous archive of seismic events.

- **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 using a second hydrogen maser and a cesium clock installed at Onsala.

## 2 Quantitative Measures of Reliability

The reliability of the OSO instruments (telescopes and geoscience equipment) is in general very high. For instance, the downtime of the telescopes due to technical failures is well below an average of 10 %. Most periods of downtime are instead caused by weather effects (rain, wind etc). The observing efficiency is particularly high for the Onsala 20 m telescope because of the radome enclosure, which makes the telescope operations immune to most weather conditions.

In general an exact efficiency value for each instrument is difficult to define. In particular, this is the case of the astronomical observations where data quality must be taken into account. The quality is for instance sensitively dependent on the (varying) weather conditions, particularly at mm and sub-mm wavelengths. In addition, the efficiency varies strongly with the complexity of the observations. This is particularly noticeable for sub-mm observations at APEX where the overhead for getting data may be a factor of three even in good weather conditions with no technical issues. In the list below, efficiency is therefore defined as the ratio between the amount of time delivering data (of acceptable quality), including overhead because of telescope movement, pointing, and calibration, and the amount of time allocated to the activity.

– Efficiency of 25 m telescope for astronomical VLBI 94 %
(time lost mainly due to weather)

– Efficiency of 20 m telescope for astronomical VLBI 72 %
(main failure was the mm-VLBI session in May)

– Efficiency of 20 m telescope for cm- and mm-wave single-dish 90 %
(time lost mainly due to weather)

– Efficiency of LOFAR station ILT observations 98 %
stand-alone mode 98 %

– Efficiency of APEX during Swedish time 88 %

– Efficiency of 20 m telescope for geodetic VLBI 92 %

– Efficiency of superconducting gravimeter 99 %

– Efficiency of aeronomy station, 22 GHz system 90 %
110 – 115 GHz system 50 %

– Efficiency of water vapour radiometers, Astrid 85 %
(no data acquired from Jan.–Aug.)
Konrad 85 %
(no data acquired from Aug. Dec. due to a failing waveguide switch)

– Efficiency of GNSS station 100 %
(based on how many days of data that have been acquired. On the other hand, individual observations, especially at low elevation angles, may be lost or suffer from low signal-to-noise ratio. Typical values are: more than 80 % of all possible observations above the horizon (0 degrees) and more than 95 % of the observations above 15 degrees have an acceptable quality.)

## 3 User Statistics

In this compilation of user statistics 'user' means an author or co-author of a proposal granted observing time during 2014 on an OSO instrument:

– Onsala 20 m telescope, single-dish: 25

Of these investigators 11 had a Swedish affiliation, 6 had not used the telescope before; Notably, the number of proposals submitted in 2014 was 20, a healthy increase from previous years, this increase was undoubtedly due to the new receiver and back-end installed on the telescope, a trend we expect to increase as papers using the new instrumentation are published. During 2014, the over-subscription rate was approximately 1.

– APEX (Swedish time), single dish: 269

Of these users 36 had a Swedish affiliation (note most projects with a Swedish affiliated user also had several non-Swedish co-Is). Of the total number of users 106 had not used APEX before on Swedish time. The oversubscription factor on Swedish time was 2.2.

- ALMA 38

  This is the number of unique Nordic users (i.e., 38 different individuals from the Nordic region) who received ALMA data during 2014. Of these, 24 had a Swedish affiliation. There was no Call for Proposals for ALMA time in 2014.

- Astronomical VLBI: 220

  The handling of proposals, scheduling, etc. is done centrally, mainly through the EVN. OSO does not have direct access to all statistics but we have been informed that in 2014, there were 220 individual users of the EVN (including e-VLBI) and GMVA (The Global mm-VLBI Array). Eleven of these had a Swedish affiliation. Most VLBI projects included at least one of the Onsala telescopes. The EVN oversubscription rate was 1.8.

- LOFAR: 41 ILT projects (number of users unknown)
  8 users in stand-alone mode (3 Swedish)

  The Onsala LOFAR station spends >90 % of its time operating as part of European network of antennas and a small amount of time operating as a stand-alone station. For the former proposals are submitted centrally to the ILT (International LOFAR Telescope) with headquarters at ASTRON in the Netherlands. Within this time the Executive committee of the LOFAR-Sweden consortium (freely open to membership to all Swedish scientists, see http//lofar-se.org) allocates the Swedish guaranteed time (4.5 % of the total).

The following geoscience instruments deliver data through various archives:

- Geodetic VLBI: Observations are performed as a service to the global geodesy community, i.e., the observations are not performed for particular scientific projects. Given this operational mode it is not possible to give the number of users. Geodetic VLBI defines the global geodetic reference system, which is used by a very large number of research projects (e.g., in remote sensing). It can be noted though, that at least 5 refereed publications were based on geodetic VLBI data including the Onsala 20 m telescope in 2014.

- The Onsala Aeronomy Station: Mesospheric water vapour data from 2014 is delivered to the international Network for the Detection of Atmospheric Composition Change (NDACC).

- Gravimeter Laboratory: Through an http address, gravimeter data with one-second samples and maximum two minutes latency is publically available. On a monthly basis, one-minute data is transferred to the GGP's archive at GFZ Potsdam (Germany). GGP is a collaborative effort, an Inter-commission Project of the International Association of Geodesy (IAG).

- The GNSS data are available through the SWEPOS (http://swepos.lmv.lm.se/), and International GNSS Service (IGS) (http://igscb.jpl.nasa.gov/) archives.

# 4 Peer-reviewed Papers

The list below give the number of papers in refereed journals based on the OSO instruments appearing in 2014 (the numbers are minimum, publications may have been missed):

- Onsala 20 m telescope, single-dish: 4
- APEX, single dish[1]: 74
- SEST, single-dish[2]: 11
- ALMA[3] 9
- Astronomical VLBI: 20
- LOFAR[4]: 11
- Odin aeronomy[5]: 9
- Geodetic VLBI[6]: 5
- GNSS, tide gauge, gravimeter, radiometers[6]: 3

1) Includes Swedish, ESO and MPI time; because OSO contributes to the full APEX operations and because the Swedish SHeFI instrument is used by all partners.
2) The Swedish-ESO Submillimetre Telescope (SEST), an equal collaboration between ESO and OSO was taken out of operation in 2003.
3) These are the ALMA papers in which the Nordic ARC node helped the authors with observation preparation or with data reduction.
4) In addition, there is a large number of publications discussing future observations with LOFAR.
5) Odin aeronomy is mentioned here since OSO played a technically important role in this satellite project.
6) These data are also used in other ways than scientific publications. It is one of the main goals for geodetic VLBI to define the global geodetic reference system, which is used by a very large number of research projects (e.g., in remote sensing from the ground and from space accurate positioning is often a necessity). In a similar way GNSS data define geodetic reference frames for regional scales (land surveying).

There are in addition to the above papers a further eight refereed publications by OSO staff on R&D within the areas of mm/submm instrumentation and methods, antenna systems, etc.

# 5 Selected Scientific Highlights

Below follows a list of scientific highlights selected to illustrate the different instruments and science areas covered by OSO.

## *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.

### 5.1 Onsala 20 m telescope single dish

Wirström et al. (2015 in prep) used the 20 m telescope to follow-up the Herschel Space Observatory discovery of the first gas phase water emission detected in a cold, dark galactic molecular cloud not associated with any proto-stellar activity. The Herschel observations targeted methanol-emission peaks in at two positions in the Barnard 5 (B5) molecular cloud. Models show that an efficient desorption of water and methanol ices in a dark cloud environment can induce the efficient formation of complex organic molecules in the gas phase. Consequently, Wirström et al. used the new high sensitivity 3 mm receiver on the 20 m telescope to search for one line from formic acid (HCOOH) and two lines from

acetaldehyde ($CH_3CHO$) at ≈90 GHz towards the two methanol peaks in B5. These observations resulted in the detections of HCOOH toward both positions and $CH_3CHO$ toward the methanol hotspot position (Fig 1, left panel). According to chemical models even more complex molecules should be present at the B5 hotspot as well as in other dark clouds. Depending on the nature of the desorption mechanism, these more complex molecules may be observable in future spectral scans using the new 4 GHz bandwidth spectrometer on the 20m telescope.

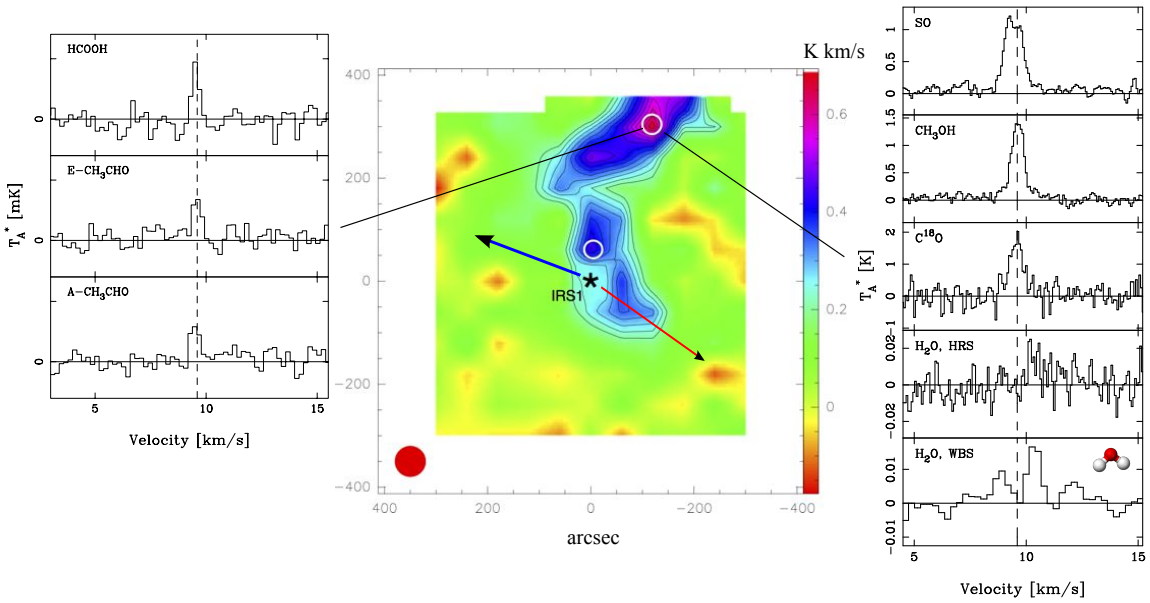



***Figure 1***. *Left and Right panels show respectively spectra from the 20 m telescope and Herschel Space Telescopeof multiple molecular species toward the methanol hotspots in the dark cloud Barnard 5 (Wirström et al., to be submitted).. These observations were one of the first experiments to use the new 3 mm receiver on the 20 m telescope. Mid panel: For context an Arizona Radio Observatory 12 m telescope integrated intensity map of A-$CH_3OH$ at 96.74 GHz. The star marks the position of IRS1, while the white rings show the relative size of the Herschel beam centred at two positions observed by Herschel, the northern one being the methanol hotspot.*

A long-term project led by Joncas et al. to map carbon monoxide emission in high-galactic-latitude clouds using the 20 m telescope continued during 2014. The data so far collected have revealed unexpectedly complex velocity fields and cloud structures (for example see the cloud sub-region map shown in Fig 2). These results, together with other observations tracing the atomic gas and dust contents, provide unique means to study the very early stages of molecular cloud formation.

Desmurs et al. (A&A 565, 127, 2014) presented long-term 20 m telescope monitoring observations of the v=1, 2, and 3, J=1–0 maser transitions of SiO in several AGB stars together with VLBI data. The 20 m monitoring data were used to trigger the VLBI imaging observations (made using the US Very Long Baseline Array, VLBA, network) at periods of flaring activity. In total 19 AGB stars were observed with the 20 m telescope over three years, with each star observed in up to 12 observing runs. The triggered VLBA imaging shows that the SiO v=3 maser emission is distributed in ring-like patterns, coincident or slightly inside those of the v=1 and 2 transitions. This result is explained in models as being due to the wider range of density conditions which give rise to v=1 and 2 maser lines after taking into account the overlapping $H_2O$ and SiO IR lines which pump these transitions.

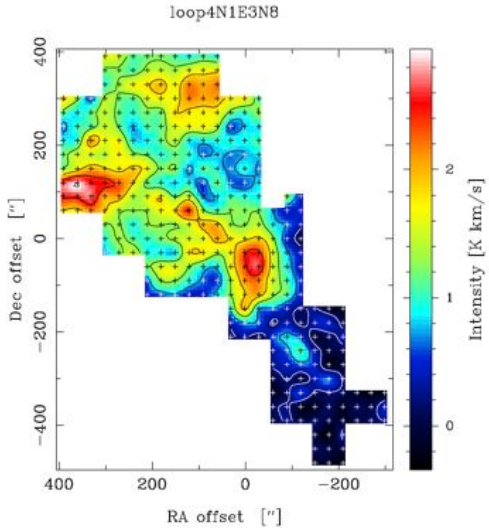



***Figure 2***. *Mapping of $^{12}$CO within part of a high-galactic-latitude molecular cloud using the 20 m telescope (Joncas et al). The goal of this project is to find and study molecular clouds being formed. Note the richness of the internal structure within this nearby cloud.*

Ramstedt & Olofsson (A&A 566, A145, 2014) used both the 20 m and APEX telescopes to determine the circumstellar $^{12}$CO/$^{13}$CO ratios in a large sample of M-type, S-type, and carbon asymptotic giant branch (AGB) stars, Fig. 3. This study contains the largest sample of stars ever studied in this way, allowing for a statistical analysis of the evolution of stars on the AGB. The authors found that the $^{12}$CO/$^{13}$CO abundance ratio changes between the different chemical types, consistent with stellar evolution models in which these spectral types delineate an evolutionary sequence. Surprisingly no correlation is found between the $^{12}$CO/$^{13}$CO abundance ratio and the mass-loss rate. This result indicates that mass loss rate does not increase with age along the AGB, contrary to what models predict

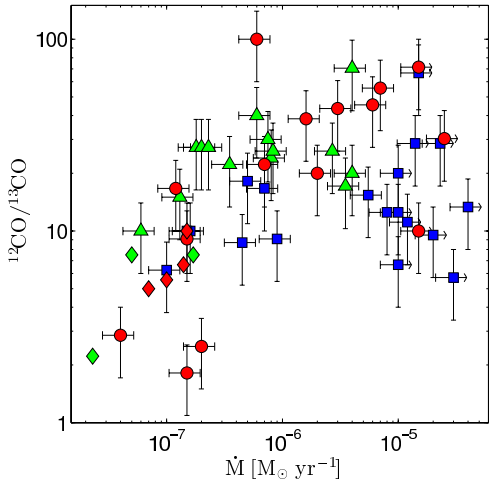



***Figure 3.*** *Circumstellar $^{12}$CO/$^{13}$CO ratios with errors as a function of mass-loss rate ($\dot{M}$) for a sample of AGB stars (Ramstedt & Olofsson 2014). The different spectral types are shown as different colours i.e. M-type stars (blue squares), S-type stars (green triangles), carbon stars (red circles). Lower limits are shown as diamonds in the corresponding colours.*

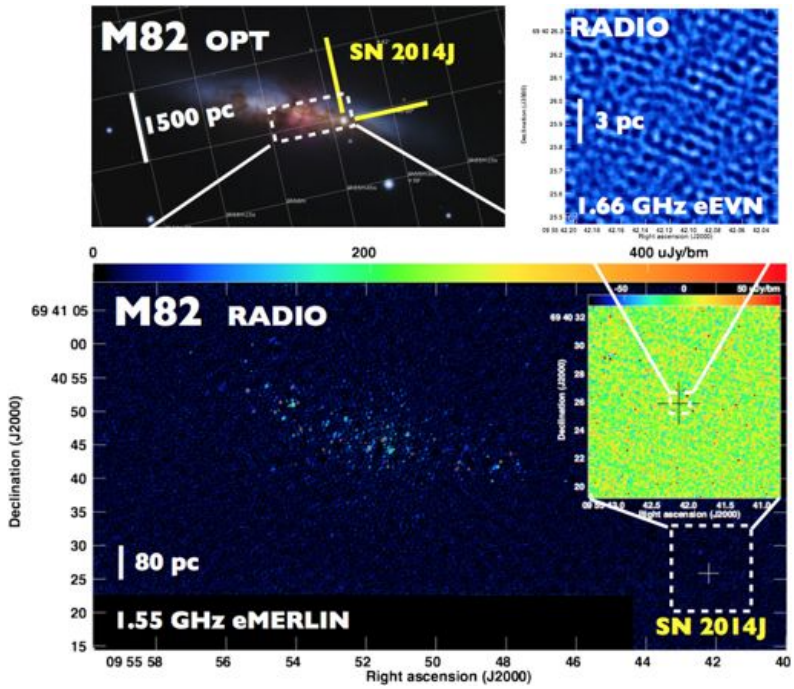



***Figure 4.*** *Observations of SN2014J and its host-galaxy M82 (Pérez-Torres et al., 2014 Optical (top left), eMERLIN (bottom), and EVN (top right).*

## 5.2 Astronomical VLBI

Pérez-Torres et al. (ApJ 792, 38, 2014) used deep EVN observations to constrain the progenitor system and the environment around the type Ia supernova SN2014J (see Fig 4). The authors combined EVN and eMERLIN observations to obtain the most sensitive limits on the radio luminosity of a type Ia SN ever achieved. Modelling of the radio emission then sets upper limits on the progenitor mass-loss rate and the density around the SN. The radio upper limits are consistent with a double-degenerate scenario for the origin of type Ia supernovae which would involve two white dwarf stars as the progenitor system to SN2014J.

Varenius et al (A&A 566, 15, 2014) presented two-frequency MERLIN and EVN observations of the core of the galaxy NGC 4418, which is one of the most obscured luminous infrared galaxies (LIRGs) in the nearby Universe. This nucleus contains a rich molecular gas environment, has an unusually high ratio of infrared-to-radio luminosity, and is either powered by a compact starburst or an active galactic nucleus (AGN). The VLBI-scale nuclear radio structure of NGC 4418 was found to consist of eight compact (<49 mas, i.e., <8 pc) features spread within a region of 250 mas, i.e. 41 pc. An inverted spectral index $\alpha \geq 0.7$ ($S_\nu \propto \nu^\alpha$) was fitted to the compact radio emission. The complex morphology and inverted spectrum of the detected compact features is evidence against the hypothesis that an AGN alone is powering the nucleus of NGC 4418. The compact features could be super star clusters with intense star formation, and their associated free-free absorption could then naturally explain both their inverted radio spectrum and the low radio-to-IR ratio of the nucleus. In order to power the radio emission via electrons accelerated in supernovae the required star formation rate per unit area is extreme. This star formation density is close to the observational limit expected for a well-mixed thermal/non-thermal plasma and is also close to the limit of what can be physically sustained dynamically.

Chomiuk et al. (Nature 514, 339, 2014) reported high-resolution radio imaging of the γ-ray-emitting nova V959 Mon (see Fig 5). They found that the ejecta in this nova is shaped by the motion of the binary system: some gas being expelled rapidly along the poles as a wind from the white dwarf, while denser material has drifted out along the equatorial plane, propelled by orbital motion. At the interface between the equatorial and polar regions the observed synchrotron emission is indicative of shocks and relativistic particle acceleration, thereby also pinpointing the location of the γ-ray production. Binary shaping of the nova ejecta and associated internal shocks are expected to be widespread among novae, explaining why many novae are γ-ray emitters

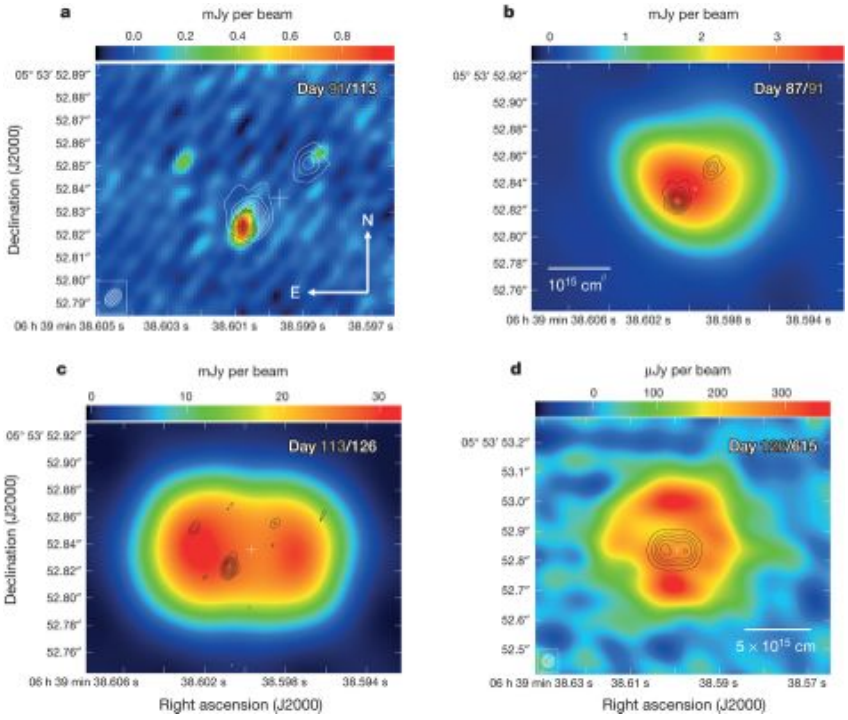



***Figure 5***. *Radio imaging of V959 Mon (Chomiuk et al. 2014). (a) The EVN images at age 91 days (contour lines) and 113 days (in colour) after the gamma-ray discovery. These images show the compact radio knots expanding diagonally. (b) e-MERLIN image of the ejecta from the nova explosion (in colour) from 87 days after discovery with the EVN contours from day 91 superimposed. (c) The same components as (b) but this time imaged with the VLA 126 days after discovery (in colour) and EVN at day 113 (contours). (d) VLA image after 615 days (in colour) with contours from the day 126 image which shows how the nova ejecta has expanded and how the major axis of the radio emission flips from E-W (horizontal in image c) to N-S. Scale bars assume a distance of 1.5 kpc and the white cross is the presumed location of the central binary system.*

Over one hundred trigonometric parallaxes and proper motions for masers associated with young, high-mass stars have been measured within the Bar and Spiral Structure Legacy (BeSSeL) Survey project of the VLBA plus EVN and Japanese VLBI astrometry observations by Reid et al. (ApJ 783, 130, 2014). The current data already identifies multiple spiral arms (se Fig 6). Maser positions, distances, proper motions, and radial velocities yield complete 3D kinematic information. By fitting the measurements to a model of the Galaxy, the authors derive the distance to the Galactic Centre and the circular rotation speed at the Sun's galactic radius giving respectively, $R_0 = 8.34 \pm 0.16$ kpc and $Q_0 = 240 \pm 8$ km/s.

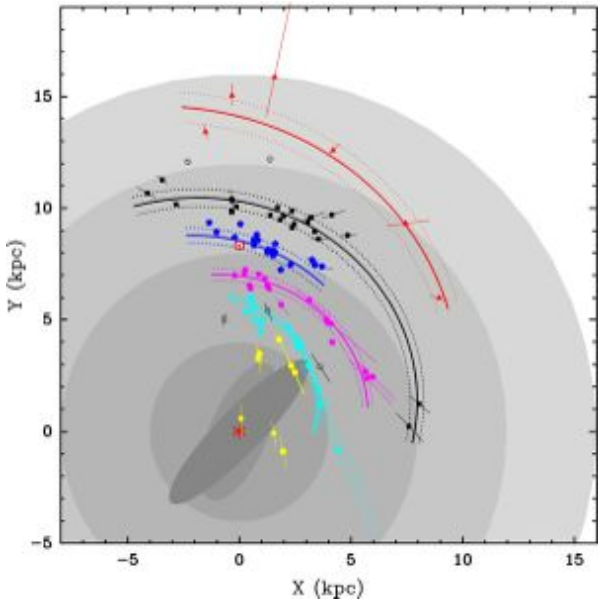



***Figure 6***. *Plane view of the Milky Way showing the locations of high-mass star-forming regions with trigonometric parallaxes measured by the VLBA, VERA, and the EVN (Reid et al 2014).*

## 5.3 LOFAR

Varenius et al. (A&A 574, 114, 2015) produced a final published version of the first high dynamic range complex image made using LOFAR's international 1000 km baselines. The image (see Fig. 7) shows the centre of the starburst galaxy M82 at a distance of 3.5 Mpc. The data for this image used the Onsala LOFAR station, four stations in Germany, and one each in the UK and France. In addition, all the Dutch LOFAR stations were used. The maximum 1000 km baselines allowed a resolution of 0.3" to be achieved with an image noise of 150 μJy per beam, at a wavelength of 1.9 m. The resulting multi-scale image covers

***Figure 7.*** *International LOFAR Telescope (ILT) image of the nucleus of the starburst galaxy M82 (Varenius et al.2015). The image is a composite of 154 MHz (blue) and 118 MHz (orange) images and has a resolution of 0.3" and a noise of 150 μJy per beam.*

about 3 kpc and shows compact unresolved supernova remnants embedded in diffuse emission. The diffuse emission is suppressed in the midline of the star-forming disk due to free-free absorption, while brighter emission is found above and below the disk. The radio continuum spectra of the compact sources show a variety of shapes implying that the free-free absorption is patchy. Detailed analysis of the spectra of both the diffuse and compact components constrains the distribution of ionised gas in the center of this starburst galaxy. This image of M82 demonstrates that, despite ionospheric propagation effects, high-resolution high-sensitivity images can be made at metre-wavelengths; both using the baseline lengths envisioned for SKA1-low (80 km) and also using longer many thousand km baselines that could be deployed in the later stages of the SKA project.

Moldón et al. (A&A 574, A73, 2015) presented a LOFAR long-baseline snapshot calibrator survey of a small area of the sky. The objective was to determine the density of suitable calibrators for international LOFAR observations. A total of 630 sources were observed in two fields with the LOFAR international stations. It was found that a number of properties of higher frequency or lower-angular-resolution data are correlated with the likelihood of being a suitable calibrator. In addition, it was found that a high flux density, a flat low-frequency spectrum, and compactness were all useful predictors of calibrator suitability. The spectral index at higher frequency, in contrast, is a poor predictor. The determined sky density of compact calibrators (about one per square degree) is thought to be sufficient to calibrate the ionosphere and allow noise limited imaging of weak sources at any position on the sky. The observing mode demonstrated by Moldón et al is now being used to observe the whole Northern sky to provide a calibrator catalogue for international LOFAR observations.

## 5.4 APEX

Fuhrmann et al. (MNRAS 441, 1899, 2014) presented results from a long-term blazar monitoring project on APEX. A correlation of the variability of blazars in the radio/sub-mm band and in the γ-ray activity was found. The time delays between the observed activity at different wavelengths provides information on where the γ-ray emitting region is located with respect to the central massive black hole. The multi-wavelength work of Buson et al. (A&A 469, A55, 2014) used part of the above data to study the flare of the blazar PKS 1424-418. The detailed monitoring at high energy and at millimetre to radio wavelengths of individual blazars is helping to reveal the mechanisms at work in blazar physics.

Using Herschel and APEX data, Wiegert et al. (A&A 563, A102, 2014) attempted to determine the debris disc properties around the nearby α Centauri solar-type binary system (see Fig 8). This study allows upper limits to be set on the amount of circumstellar dust associated with this system.

Ramstedt & Olofsson (A&A 566, A145, 2014) used both the APEX and 20 m telescopes to determine the circumstellar $^{12}CO/^{13}CO$ ratios in a large sample of M-type, S-type, and carbon asymptotic giant branch (AGB) stars (this result is described more fully in section 5.1).

Cormier et al. (A&A 564, A121, 2014) used single-dish data from APEX, IRAM 30 m, and MOPRA telescopes taken toward a sample of dwarf galaxies, and combined them with Herschel data. Their results confirm that CO suffers strongly from destruction by photo-dissociation in low-metallicity dwarf galaxies.

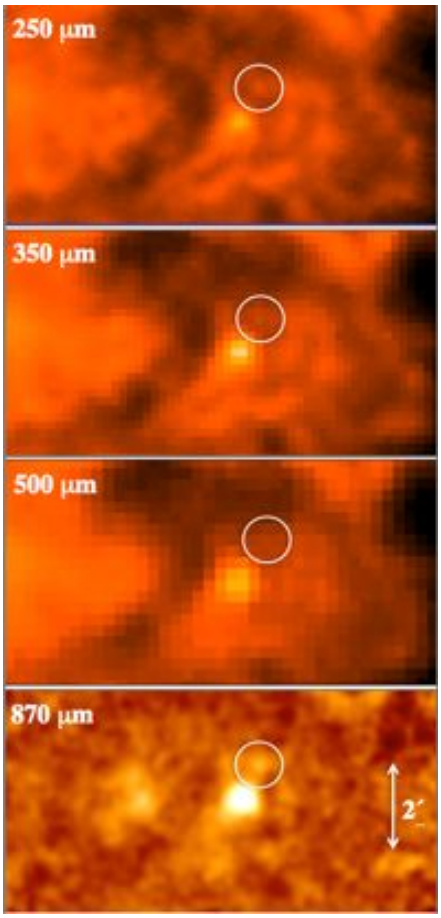



***Figure 8.*** *Continuum maps toward the nearby star α Cen (Wiegert et al. 2014). The APEX Laboca bolometer array map is at the bottom, the three upper maps are from Herschel SPIRE. In the Laboca map, the dust around α Cen is clearly detected (inside the ring) but the binary components are not resolved. The brighter source outside the ring is likely related to continuum emission associated with a molecular cloud.*

Using APEX SHFI and IRAM 30 m telescope data, Groenewegen (A&A 561, L11, 2014) reported the first detection of CO rotational line emission toward a red giant branch (RGB) star. The line intensity is very low due to the low mass-loss rate (only a few times $10^{-9}$ $M_{sun}$/yr), and further studies would require instruments like ALMA. The measured circumstellar gas expansion velocity of 12 km/s is surprisingly large for an RGB star.

Brünken et al. (Nature 516, 219, 2014) used APEX-FLASH and SOFIA $H_2D^+$ data to determine the age of a cloud core which is presently forming sun-like stars. By observing the spin-isomer ratio of the $H_2D^+$ molecule (a deuterated version of the astrochemically very important ion $H_3^+$) it is found, in conjunction with chemical models, that the core gas has been processed for at least $10^6$ yrs. This is about one magnitude longer than previously thought. Since the age of molecular cloud cores is a fundamental parameter in star formation scenarios this finding has a major impact on the time available for collapsing molecular cores in star-formation models.

## 5.5 ALMA observations supported by the Nordic ARC node.

ALMA CO observations have shown the complex interplay between the binary stars Mira A and B (Ramstedt et al., A&A 570, L14, 2014), see cover figure and Fig 9. This image was made using the main ALMA array plus ALMA Compact Array (ACA) of 7 m dishes plus data from APEX. The data from APEX were invaluable in sampling the largest scale structure. The AGB star Mira A (Mira Ceti) has long been known to have a slow wind, and ALMA has now confirmed that Mira B (which is a hot, dense white dwarf star) has a strong and fast stellar wind. The observations show how the winds from the two stars have combined to create a fascinating, beautiful, and complex nebula. The remarkable heart-shaped bubble at the centre is created by Mira B's energetic wind inside Mira A's more relaxed outflow. The heart, which formed some time in the last 400 years, and the rest of the gas surrounding the pair show that they have long been building this strange environment together. By looking at stars like Mira A and B it is possible to demonstrate how double stars can influence their environments.

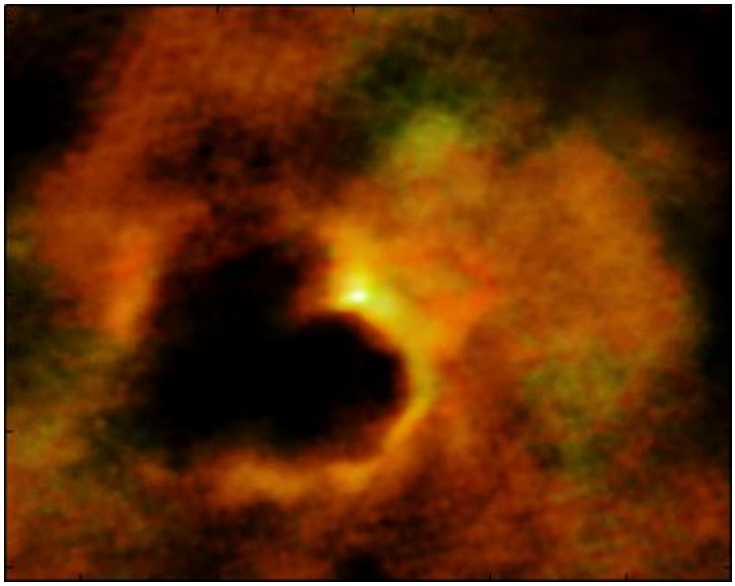


***Figure 9***. *ALMA + APEX CO(J=3-2) image of the circumstellar gas around the red giant star Mira Ceti and its companion (Ramstedt et al. 2014). This is a detail of the full image shown on the front page of this document. Different colours correspond to different gas Doppler velocities. This detailed image shows the heart shaped cavity created by the combined outflows of the AGB star Mira A and its white dwarf companion Mira B.*

With ALMA, Muller et al. (A&A 566, L6, 2014) made the first extragalactic detection of chloronium ($H_2Cl^+$) in the z = 0.89 absorber in front of the lensed blazar PKS 1830-211, Fig 10. The ion is detected along two independent lines of sight toward the NE and SW images of the blazar. The relative abundance of $H_2Cl^+$ is significantly higher (by a factor ≈7) in the NE line of sight, which has a lower $H_2$/H fraction, indicating that $H_2Cl^+$ preferably traces the diffuse gas component. It is found that the $^{35}Cl/^{37}Cl$ isotopic ratio is ≈ 3.1 at z = 0.89, similar to that observed in the Galaxy and the Solar System.

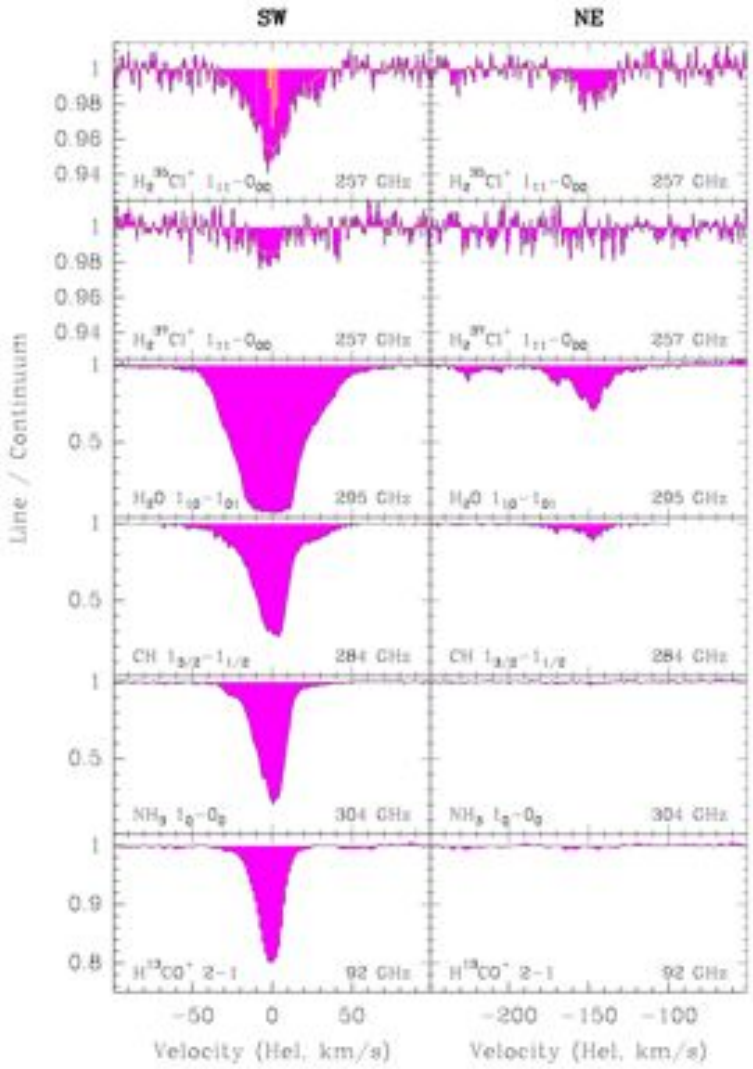



***Figure 10.*** *From Muller et al. (A&A 566, L6, 2014) spectra of the $H_2{}^{35}Cl^+$ and $H_2{}^{37}Cl^+$ $1_{11} - 0_{00}$ line and other molecular species, all observed by ALMA towards the PKS 1830−211 gravitational lens SW and NE images (left and right columns respectively).*

ALMA observations of young stars in the R CrA cloud, processed with the help of the Nordic ARC node, have likely revealed one of the youngest proto-planetary disks showing Keplerian rotation. By observing isotopic $C^{17}O$ line emission, Lindberg et al. (A&A 566, A74, 2014) found a <50 AU diameter disk of mass approximately 0.024 solar masses. This disk appears to dominate the small-scale chemistry and can explain why this and other similar sources do not show significant emission from complex organic molecules, which is a normal characteristic of such hot inner envelopes.

## *Geosciences*

### 5.6 Tropospheric delay ray tracing applied in VLBI analysis

Ray tracing through numerical weather model data was used to calculate a priori tropospheric delays that were applied in the VLBI data analysis. Using this approach for e.g. the CONT11 campaign and global data sets improved the baseline repeatability, compared to the use of other a priori tropospheric delays (Eriksson et al., J. Geophys. Res. Solid Earth 119, 9156, 2014).

## 5.7 GNSS

Global Navigation Satellite System (GNSS) signals from different satellite systems, i.e., multi-GNSS, were measured with the Onsala GNSS-R tide gauge. Two complementing analysis strategies were used to derive local sea level with commercial geodetic GNSS equipment. Time series of the resulting GNSS-derived sea level were compared with results from co-located traditional tide gauges (Fig. 11 below summarizes the results). The variations in the sea level estimated from the GNSS data, gave high correlations (up to 0.97) and low standard deviations (3–4 cm) compared to the results from traditional techniques (Löfgren & Haas, EURASIP Journal on Advances in Signal Processing 2014, 2014:50). The advantage of this novel sea-level-monitoring technique is that one instrument can measure both land motion and sea-level motion, either separately or together. By combining these two measurements, it is possible to measure the absolute sea level, i.e., the sea level with respect to the International Terrestrial Reference Frame (ITRF).

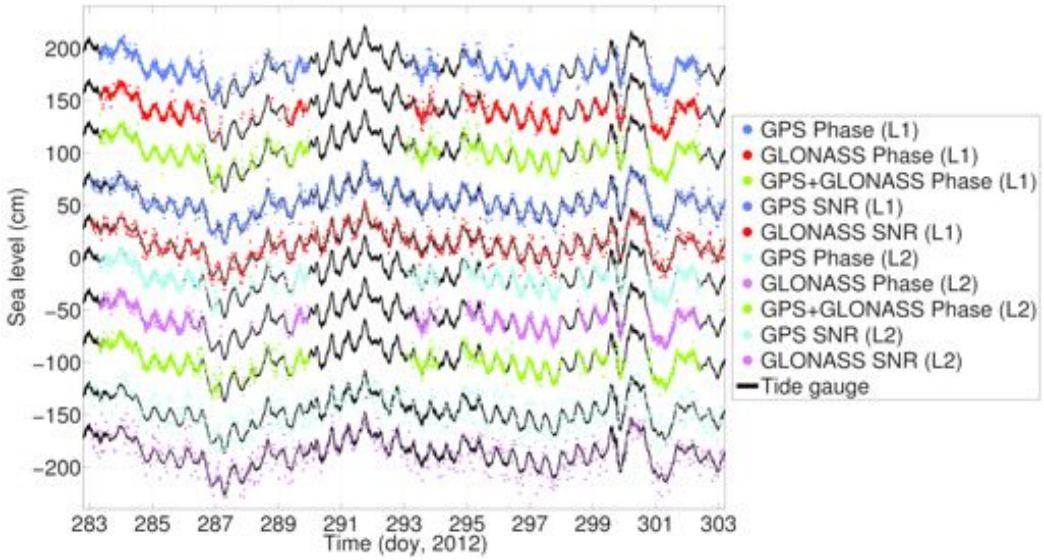



***Figure 11.*** *Sea level derived from the GNSS tide gauge at the Onsala site during 20 days in 2012 (Oct. 9 to 29). From top to bottom the sea level times series are derived from: GPS phase ($L_1$), GLONASS phase ($L_1$), GPS and GLONASS phase ($L_1$), GPS SNR ($L_1$), GLONASS SNR ($L_1$), GPS phase ($L_2$), GLONASS phase ($L_2$), GPS and GLONASS phase ($L_2$), GPS SNR ($L_2$) and GLONASS SNR ($L_2$). Each time series is paired with the independent sea level observations from the co-located tide gauge (black line). A mean is removed from each time series and the pairs are displayed with an offset of 40 cm to improve visibility.*

A new reflectometry instrument that focuses on GLONASS signals was compared to the Onsala GNSS-R tide gauge (Hobiger et al., Radio Science 49(4), 217, 2014). The new system is based on rather inexpensive commercially off-the-shelf equipment. It was shown that the precision and accuracy of the GLONASS-R system is comparable to that of the existing GNSS-R.

The SNR-based approach to analyse multi-path signals of GNSS stations has been used to derive sea level for a number of coastal GNSS stations worldwide. The derived sea level time series were compared to information from co-located traditional tide gauges.

Additionally, harmonic analyses were performed to determine ocean tidal amplitudes and phases. The results prove that the technique allows a sea-level determination with a relative accuracy of 2–10 % when compared to the co-located traditional sensors (Löfgren et al., J. of Geodynamics 80, 66, 2014).

## 5.8 Geodetic VLBI

A model was developed to describe the deformation of radio telescopes used for geodetic VLBI and the impact of this on geodetic VLBI observations (Artz et al., J. of Geodesy 88(12), 1145, 2014). The model was aimed primarily at the large radio telescope in Effelsberg, but is also applicable to other telescopes. The model was evaluated using analysis of a global VLBI data set including Onsala data.

The recommended IAU models for precession and nutation have been studied using global VLBI data sets, including Onsala data (Malkin, Astron. Rep. 58(6), 415, 2014). The results show that the current temporal interval of VLBI observations only allows for the improvement of nutation and precession model parameters to first order, i.e., shifts and rates, but not higher-term parameters.

The continuous VLBI campaign CONT11 was analysed to study various aspects of Earth orientation. It was shown for example that the currently recommended models for high-frequency Earth orientation variations have deficits that need to be improved (Nilsson et al., J. of Geodesy 88(5), 491).

Data from VLBI and GNSS were analysed together with a new approach that combines the data at the observation level. It was shown that this approach benefits from the individual strengths of the different techniques and more robust results can be derived than when analysing the techniques individually. Using such techniques it is found that station position and tropospheric parameters are consistently and significantly improved (Hobiger & Otsubo, J. of Geodesy 88(11), 1017, 2014).

## 5.9 Superconducting Gravimeter

From May 29th to 31st, 2014, a series of parallel recordings were made comparing the FG5 absolute gravimeters from Leibniz University (Hannover, Germany) and Lantmäteriet (Gävle) with the Onsala superconducting gravimeter (SCG). Results from this campaign and an earlier campaign from 2009 onwards have been reported at the General Assembly of the Nordic Geodetic Commission (NKG) in Göteborg in Sep. 2014. Figure 12 shows the measurements from the Onsala SCG and the Hannover FG5-instrument.

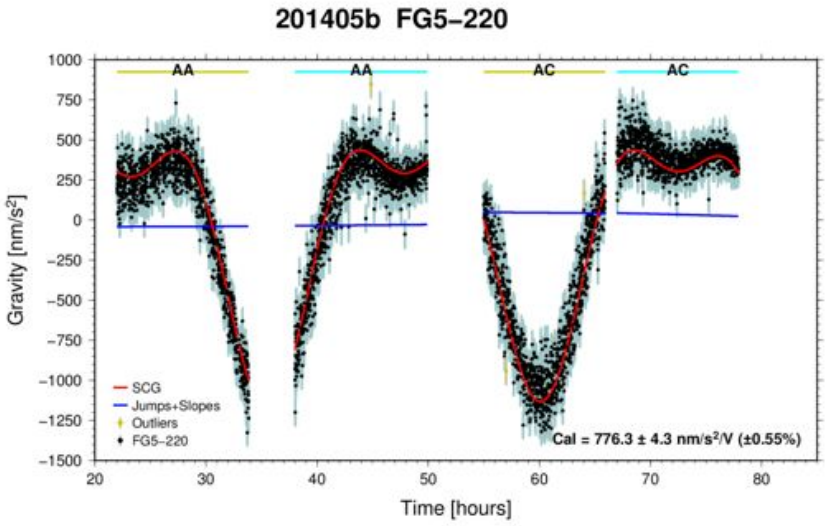



***Figure 12.*** *Parallel recording of superconducting gravimeter (SCG, red) and absolute gravimeter FG5-220 (Hannover) May 29-30, 2014. The latter is shown as black dots with standard deviations (blue bars). In the four segments of the figure the orientation of the FG5 was swapped North-South-North-South from the left to the right in order to assess any bias incurred by the Coriolis force. The calibration factor of the SCG was estimated from the peak to peak variation of the series, which is predominantly due to Earth tides.*

# 6 Technical R&D

## 6.1 Millimetre/sub-millimetre devices

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

From June 2012 GARD has been involved in the three-year EU-funded RadioNet3 Joint Research Activity AETHER (Advanced European TeraHertz Heterodyne Receivers) to work on advanced IF components for sideband-separating SIS (Superconductor-Isolator-Superconductor) mixers and balanced HEB (Hot Electron Bolometer) mixers for array receivers. This work is done as part of a collaborative effort with Institute Radioastronomie Millimetrique (IRAM) (France), which is responsible for the mixer development, while GARD provides the IF hybrid development, design, and fabrication. In particular, GARD has been working on 4 – 12 GHz solid-state superconducting IF hybrids and power combiners for such receivers (see Fig 13). A batch of combiner chips have been fabricated and characterised in-house. These chips show excellent performances from 1 to 10 GHz and are found suitable for wide IF, balanced HEB mixer receivers.

Another important component of mm receiver systems is the RF-waveguide hybrid; this component can have a high impact on the receiver sideband rejection, and hence the final receiver sensitivity. Based on the work performed in 2013, when the innovative RF hybrid design was introduced by GARD, this solution was implemented in the production of the ALMA Band 5 receiver cartridge (see Fig 14).

GARD continued to work on the previously demonstrated new approach to construct THz HEB mixers, where the active element is micro-machined using a so-called π-frame, and the waveguide is micro-machined using a moulding technique with thick photoresist. These technologies are now being implemented in the second generation of the APEX T2 receiver, 1.25 – 1.39 THz, which might in the future be mounted within the new APEX SEPIA instrument, or possibly be used in a future balloon project.

In addition to the above projects GARD has been investigating several new areas of development, each of which is at an early stage: i) work to demonstrate parametric amplification in a superconducting transmission line using the Kerr effect, ii) work to make accurate characterizations of the specific capacitance of superconducting tunnel junctions using a novel method, and involving direct measurements at microwave frequencies at 4 K, and iii) work on demonstrating effective multiplication on an SIS-based multiplier with resonant-type superconducting tunnel junctions.

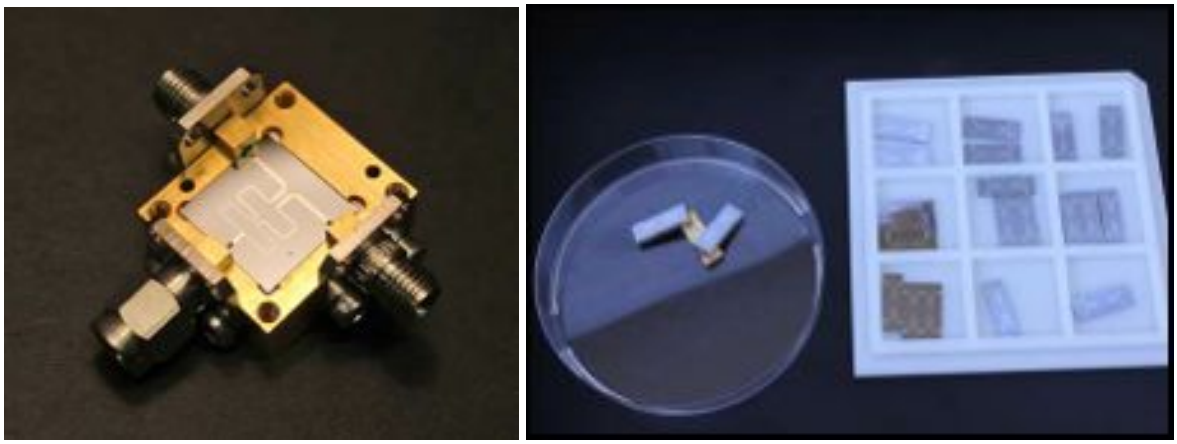


***Figure 13.*** *Left: The superconducting Wilkinson power combiner used in balanced HEB THz mixer. Right: The fabricated micro-miniature 4-12 GHz IF hybrid chips.*

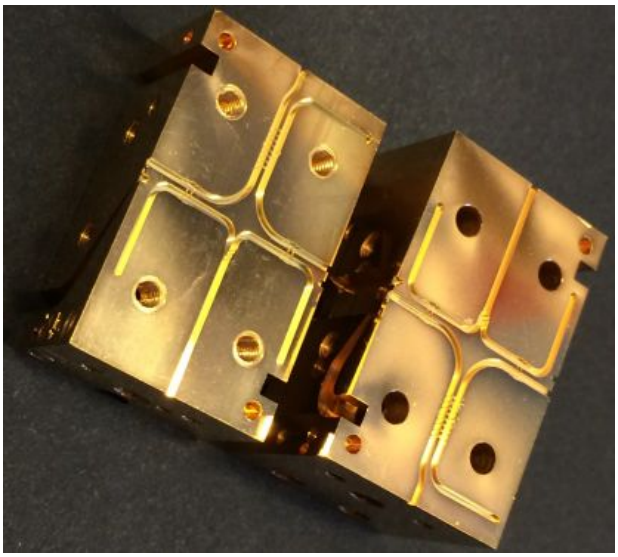


***Figure 14.*** *The waveguide part of the separating sideband ALMA Band 5 mixer with the implemented novel RF hybrid.*

## 6.2 LOFAR

During 2014, OSO experimented with a new method for determining the polarimetric response of the LOFAR antenna elements (see Fig 15). Knowledge of the response of the antenna elements is a key aspect of the telescope calibration. The results were published by Carozzi (Astronomy & Computing, in press). This paper was the first to use data exclusively from the Onsala LOFAR station.

Onsala also developed an *a priori* calibration method (a software package called "mscorpol"), which was published on the web site github. This software corrects visibility data for the antenna response and can convert data from a linear to a circular basis. This software has been used by the LOFAR long-baseline-processing pipeline and by the LOFAR pulsar groups.

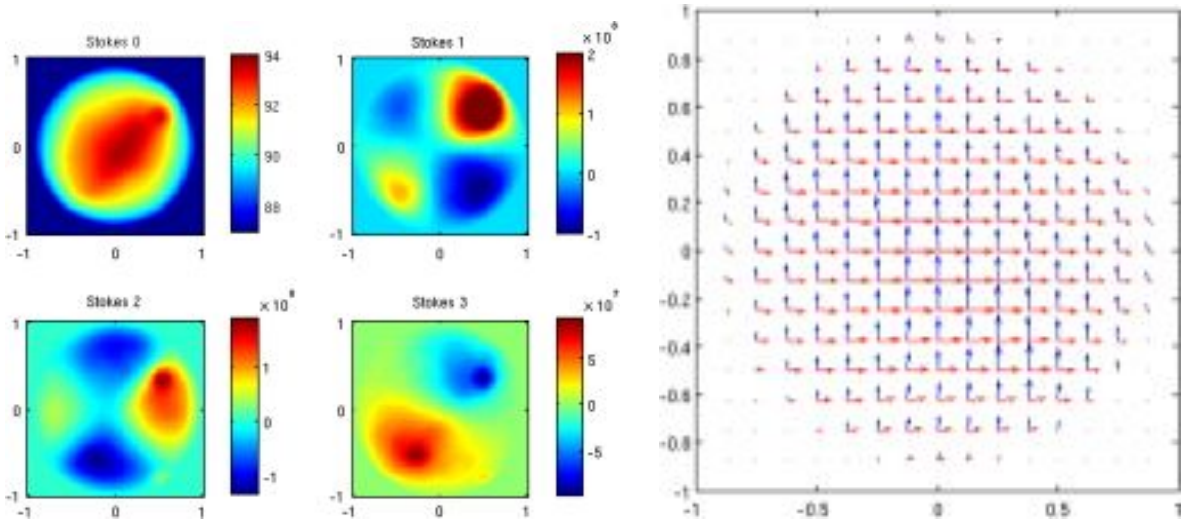



***Figure 15.*** *Left: All-sky hemisphere Stokes polarimetric images from LOFAR Low-Band Array taken with the Onsala LOFAR station on 2nd Jan. 2014 with 10 s integration at 26.27 MHz. Stokes 0, 1, 2, and 3 labels correspond to Stokes parameters I, Q, U, and V; the Stokes 0 scale is in dB while the others are linear scales in arbitrary units. The Stokes I images at the top left shows galactic emission at 27 MHz modulated by the station response. Right: Visualization of the all-sky direction-dependent Jones Matrix parameters (which describe the polarimetric response). The blue and red arrows correspond to the real part of the effective antenna length vectors of the xx and yy elements, respectively.*

## 6.3 VLBI

OSO continued the work within the EU RadioNet3 Joint Research Activity DIVA (developments for VLBI in Astronomy) during 2014. This project has two parts, and OSO is involved in both. The first part concerns the development of a broadband feed and low-noise amplifier (LNA) package for VLBI, in collaboration with MPfR (Germany), ASTRON (the Netherlands), and IAF Fraunhofer (Germany). MPIfR and ASTRON are developing the design of state-of-art LNAs, and the MMIC (Monolithic Microwave Integrated Circuit) chips for the LNAs will be processed at IAF Fraunhofer. OSO has the responsibility of integrating the LNAs with a broadband feed and performing the sensitivity tests. During 2014 the design was completed and the feed to be used for the tests was manufactured.

The second part of DIVA involves the design and testing of the third generation of a digital backend system (DBBC3 + FILA40G). The FILA40G, which has been designed at OSO, combines four individual 8 Gb/s data streams from the DBBC3, performs some processing on them as needed before either transmitting the resulting streams via a 40 GbE interface, writing to disk, or a combination of both. The FILA40G will also acts as a timekeeper for the DBBC. Software for the FILA40G is currently being finalised, with test observations using the DBBC3 + FILA40G planned for spring 2015. The aim is to fully implement digitally all the functionality required of a complete 32 Gb/s VLBI backend for the EVN and for the future geodetic VLBI system VGOS (VLBI2010 Global Observing System).

### 6.4 VGOS feeds

The next generation Geodetic VLBI observing system (VGOS) will use extremely wideband feeds and receivers. During 2014, OSO continued its collaboration with the Gothenburg-based company Omnisys Instruments AB. In return for access to final feed/receiver designs OSO provided support to the cryogenic and mechanical design of a cryostat for the integration of the broadband Eleven Feed, and further issues related to system integration. Support was also given for receiver sensitivity tests, which were performed at the Observatory during July 2014. The resulting feed is one candidate for the feed to be deployed on the Onsala Twin Telescope.

### 6.5 ALMA Phasing project

Marti-Vidal et al. (EVN Symposium 2014, in press) has further developed PolConvert, the software for the calibration/conversion of the mm-VLBI visibilities using the phased ALMA (which will observe in linear polarization unlike most other mm VLBI stations). PolConvert has been tested with realistic synthetic data and with real state-of-the-art VLBI observations at 86 GHz using the OSO 20m telescope performed in a mixed polarization basis. These observations show that it is possible to fully calibrate and convert the mixed polarization mode VLBI visibilities related to ALMA. In addition, the authors propose a special calibration algorithm, based on visibility ratios, to properly convert the visibilities to a circular basis if the station with linear receivers is a single dish.

## 7 Instrument Development and Upgrades

### 7.1 A new 3 mm/4 mm receiver for the Onsala 20 m telescope

The project to build a newjoint 3 mm/4 mm receiver for the 20 m telescope as outlined in the 2012 – 2016 observatory strategic plan is moving close to completion. The mechanical, cryogenic and most optical parts of both wavelength channels are built and installed on the telescope. Furthermore the 3 mm receiving channel is now fully commissioned and has been brought into use (see below). For single dish operation, the receiver uses an innovative on-source/off-source optical switch. Within the same optical layout this switch, in combination with additional optical components, provides two calibration loads (for the 3 and 4 mm channels respectively), sideband rejection measurements, and tuning possibilities. The 3 mm channel employs a sideband-separating dual polarization receiver with OMT and 4 – 8 GHz IF bandwidth. The work on the 4mm channel (which uses a broadband Low Noise Amplifier as its receiving element) continues; the main components yet to be completed are the IF electronics and horn. The installation and commissioning of the 4 mm channel inside the

joint 3 mm/4 mm receiver is planned for autumn 2015 with user observations planned to start by the end of 2015.

The new 3 mm/4 mm receiver assembly was first installed at the 20 m telescope toward the end of the 2013/2014 millimetre observing season in March 2014 for initial evaluation and commissioning at 3 mm. The time allotted for this activity was severely constrained due to various observational commitments. The receiver was disassembled again for minor adjustments during summer 2014 after a few 3 mm projects had been successfully completed. Telescope commissioning resumed in November and continued during schedule gaps for the remainder of the year. Tests show that the 3 mm receiver channel meets or exceeds all design specifications: it has very stable spectral baselines, low noise and good sideband rejection in both polarisations. Examples of the new receiver's performance in commissioning observations are shown in Figs 16 and 17. These figures show respectively a broadband galactic spectrum and a weak broad line from an extragalactic source. These results show that a very significant improvement in the 20 m telescope instrument capability has been achieved.

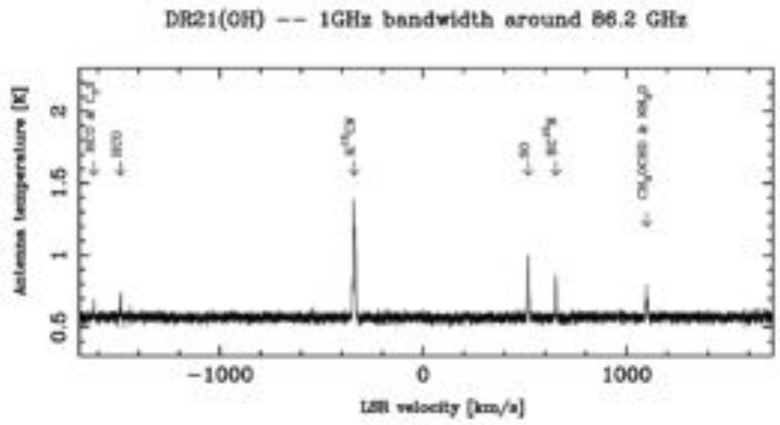



***Figure 16.*** *A broadband spectrum of molecular line emission in a galactic star-forming region with no fitted spectral baseline versus frequency subtracted (and using the then maximum bandwidth of the spectrometer backend of 1GHz; these observations used 48 minutes of on-source time on April 14). This early test was done in non-optimum conditions (partly raining and using position switching, which is more sensitive to unstable weather).*

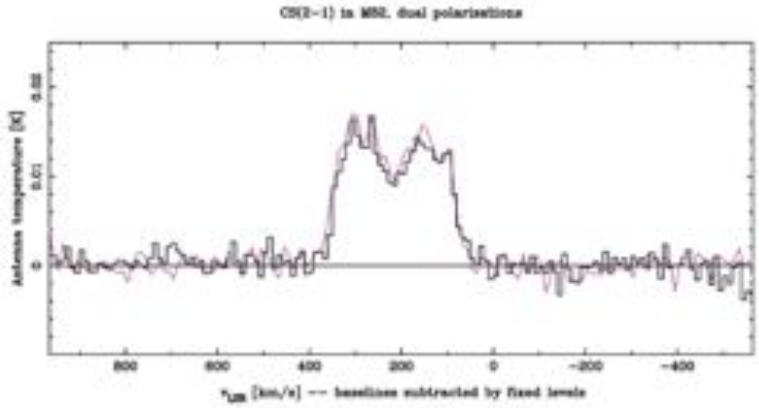



***Figure 17.*** *A CS(J=2-1) spectrum of the starburst galaxy M82 observed in beam-switch mode for 8.8 hours on-source time. These observations were made in dual polarization mode in April 2014 with the then maximum spectrometer bandwidth of 0.5 GHz. The histogram and solid lines correspond to the local horizontal and vertical polarization components.*

## 7.2 Wideband Fast-Fourier-Transform Spectrometer for the Onsala 20 m telescope

During 2014 OSO purchased a new broadband high-resolution Fast-Fourier-Transform Spectrometer (FFTS) for single-dish observations. This new spectrometer has a bandwidth of 2.5 GHz per polarization and a channel resolution of 78 kHz (it can also be configured to cover the full 4 GHz IF band of the 3 mm receiver at single polarization). The spectrometer was delivered in November 2014 and was integrated with a new broadband IF down-converter system providing the possibility to use the spectrometer with the new 3 mm receiver. The installation is on schedule to have the FFTS available for regular observations by February 2015; this will increase by a factor of four the maximum spanned bandwidth of single and dual polarization spectra compared to the results shown in Figs 16 and 17.

## 7.3 A 4 – 12.25 GHz receiver for the Onsala 20 m telescope

During 2014 design work on a 4 – 12.5 GHz cryogenic receiver for the Onsala 20 m telescope was begun. The geodetic VLBI observations at the 20 m telescope are currently conducted with a dual S/X band system with 250 MHz bandwidth.The S-band (centred at 2.3 GHz) channel uses an offset horn and a tertiary reflector that has a small dichroic window through which the X-band (centred at 8.4 GHz) horn observes. One of the limitations of this system, both for astronomy and geodesy VLBI, is that the current S- and X- band feeds do not allow for an extension of the observing bandwidth beyond 250 MHz. A new wider band S-band dual polarization system has been built in 2014 and will likely be installed during 2015. The present narrow X band receiver can likewise be replaced by a new broadband 4 – 12.5GHz dual polarization. Furthermore at present C-band (5GHz) astronomical VLBI observations are possible only with the 25m antenna but some experiments are canceled due to strong winds; the new receiver system will allow us to perform these observations even in bad weather conditions using the radome enclosed 20m telescope. Finally the new receiver will single dish spectroscopy observations over the full range of 4 – 12.5GHz including observations of the methanol lines at 6.7GHz and 12.2 GHz. Since the geometry of the 20 m telescope is designed for mm-wave optics, designing a horn feed for wide bandwidth covering the relatively low frequency range of 4 – 12.5GHz is very challenging. During 2014 a design study was ordered and delivered by the world experts in this particular type of horn at British Aerospace Systems (Australia). The delivered design will have high sensitivity and can be implemented at relatively low cost. A decision about building and deploying such a new receiver will be made during 2015.

## 7.4 LOFAR

During 2014 Onsala deployed a dedicated data recording system in order to fully utilize its LOFAR station in standalone mode. This recording system consisted of a computer with 10 Gb/s ethernet, multiple fast CPUs, a high-end GPU, and large disk space. This configuration allows the recording of beam-formed data for at least 24 hours of observations from the LOFAR station. Figure 18 shows example data on the pulsar J1509+5531.

On the software side on the above stand-alone LOFAR processing platform several new pipelines were developed. These included a pipeline to record and process transient buffer board (TBB) data. Software for station calibration was also developed and routine calibrations were carried out. Finally, a dynamic spectrum tool to monitor the spectrum of beam-formed data was developed.

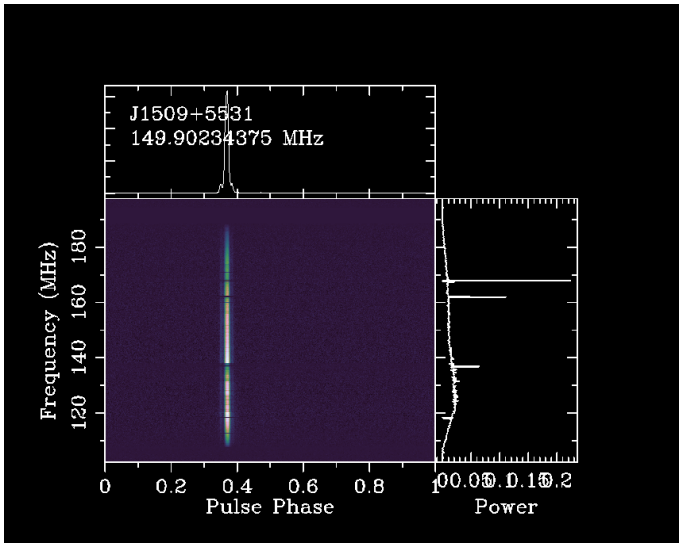



***Figure 18.*** *Pulsar data on J1509+5531 observed with the OSO LOFAR station, showing observed intensity versus pulsar pulse phase.*

## 7.5 VLBI Equipment

The old Mark4 backend was phased out during 2014 after the successful commissioning of the new VLBI system (Mark 5). With two such new Mark 5 systems deployed OSO is now able to observe routinely in VLBI mode with the 20 m and 25 m telescopes simultaneously; this means that for instance geodesy and astronomy VLBI projects can be run at the same time removing scheduling clashes. OSO has also during the year been heavily involved in the implementation and testing of the so-called FlexBuff, the next recording system for the EVN. Data are recorded locally on the FlexBuff unit and later transferred over the internet to the correlator. Converting from disk shipping to such disk-less operations has many significant operational advantages: stations such as Onsala using such equipment do not need to bother with changing and shipping disk packs and data transfers can be done practically automatically. Furthermore no disk packs need to be distributed from the correlator to each station before each observing session. Operationally such a system also allows significant sub-sets of the astronomical or geodetic VLBI networks to produce results in (near) real time.

## 7.6 APEX SHeFI service mission

The Onsala Group for Advanced Receiver Development (GARD) performed in early 2014 a service mission to APEX to upgrade the IF amplifiers in the Swedish Heterodyne Facility Instrument (SHeFI). The new amplifiers (state of the art in the world, purchased commercially from Low-Noise Factory AB, Mölndal) have been installed for the receiver channels B1, B2, and B3. The service mission was complicated by the fact that the APEX staff needed assistance for the annual cryo-cooler service (several GARD-team members were involved), and by work done to upgrade the SHeFI control computer. As a consequence, the GARD team spent more time than expected to bring the new IF amplifiers into operation. The upgraded SHeFI receiver successfully completed its observation programme during 2014. The T2 receiver channel at 1.4 THz was during the APEX board meeting in October removed from plans for the facility instrumentation. A new version of T2 may however in the future be installed in the new SEPIA cryostat (see Sect 7.7).

## 7.7 ALMA Band 5 receiver on APEX (SEPIA)

Following a mutual agreement between ESO and OSO, GARD has designed, built, and shipped to Chile a version of an ALMA Band 5 receiver cartridge (163 – 211 GHz) integrated into a 3-cartridge cryostat to be installed on APEX. This will give APEX the ability to make Band 5 observations prior to operations with this band being available for users on ALMA. The whole unit is called SEPIA (Swedish-ESO PI instrument for APEX) and encompasses an ALMA-style cryostat, optics, control system and supporting electronics (see Fig. 19). The first receiver installed in this cryostat is the pre-production version of the ALMA Band 5 receiver cartridge built by GARD during the EC FP6 Project. The local oscillator and warm cartridge for this band were delivered to the SEPIA project from the National Radio Astronomy Observatory (US) via ESO. The performance of the Band 5 receiver significantly exceeds the ALMA specifications. The SEPIA receiver is due to be installed during the next APEX shutdown period in February 2015.

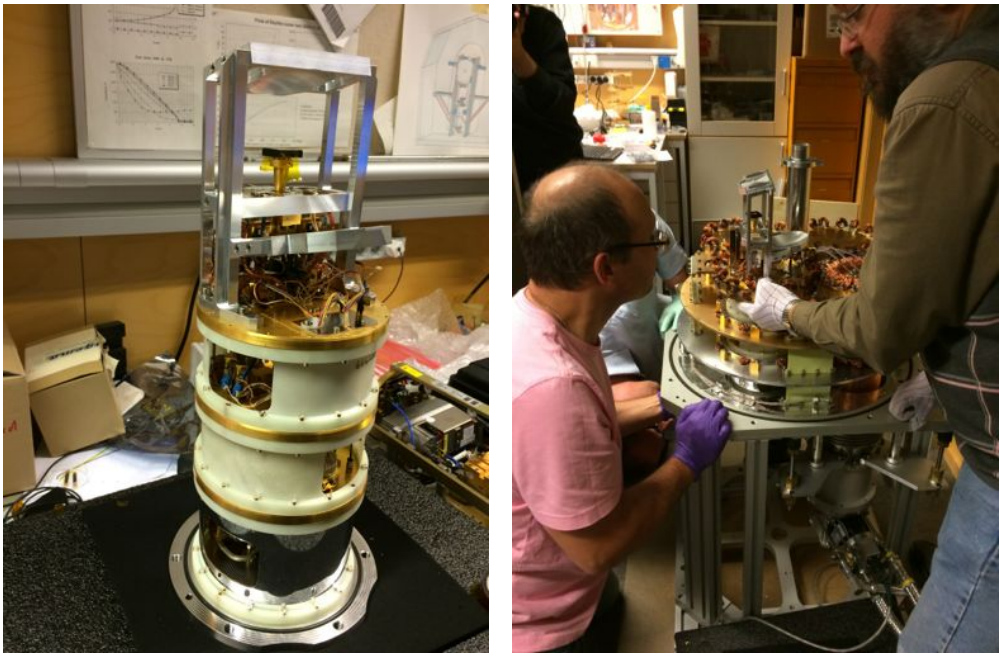


***Figure 19***. *Left: The ALMA Band 5 cold receiver cartridge before installation into the cryostat in the GARD laboratory. Right: Picture after the integration of the receiver cartridge into the cryostat.*

## 7.8 SuperCam

In November and December 2014, the 64 pixel 345 GHz heterodyne camera (SuperCam) was installed in the Cassegrain cabin at APEX. This project is a collaboration between OSO and ESO and the instrument team from Steward Observatory, Univ. of Arizona (US). Although the instrument performance was not as good as expected, it provided maps with efficiency several times that of the facility single-pixel receiver when mapping strong sources over large areas. The camera remains on the telescope site and will likely be used again during April and May 2015 (with an improved efficiency if parts of the optical system can be replaced).

## 7.9 ALMA Band 5 Full Production project

The ALMA Band 5 receiver covers the frequency range 163 – 211 GHz and is centred on the para-$H_2O(3_{13}–2_{20})$ line at 183 GHz; one of the few $H_2O$ 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). During the EU-funded ALMA Band 5 Project the OSO GARD group delivered to ALMA in Chile six Band 5 receiver cartridge assemblies; this project was successfully completed during 2013. The receivers have been tested on the site and interferometric fringes have been obtained but they have not been brought into operational use at ALMA. The technical success of this project lead to an increased interest in the full deployment of Band 5 receivers on all ALMA antennas. The ALMA Observatory Board decided in Spring 2012 to finance this project as one of the first ALMA upgrades. The plan adopted is that the operational deployment of Band 5 on ALMA will wait until the full production run is finished, so when this band is finally installed operationally it will be installed on all antennas.

In the new ALMA Band 5 full production project GARD collaborates with the Netherlands Research School for Astronomy (NOVA). A contract was signed in Februaary 2013 to produce 66 Band 5 cartridges of a slightly modified design compared to those made for the earlier EU project. The new project brings in a total of 48 Mkr of ALMA central upgrade funding to OSO/GARD in the period to the end of 2017. During 2014, the last refinements in the production cartridge design have been verified and a Manufacturing Readiness Review (May 2014) has confirmed the start of the procurement and production stages of the project. The measured noise performance of some od the first completed receivers is shown in Fig. 20; as can be seen it significantly exceeds specifications.

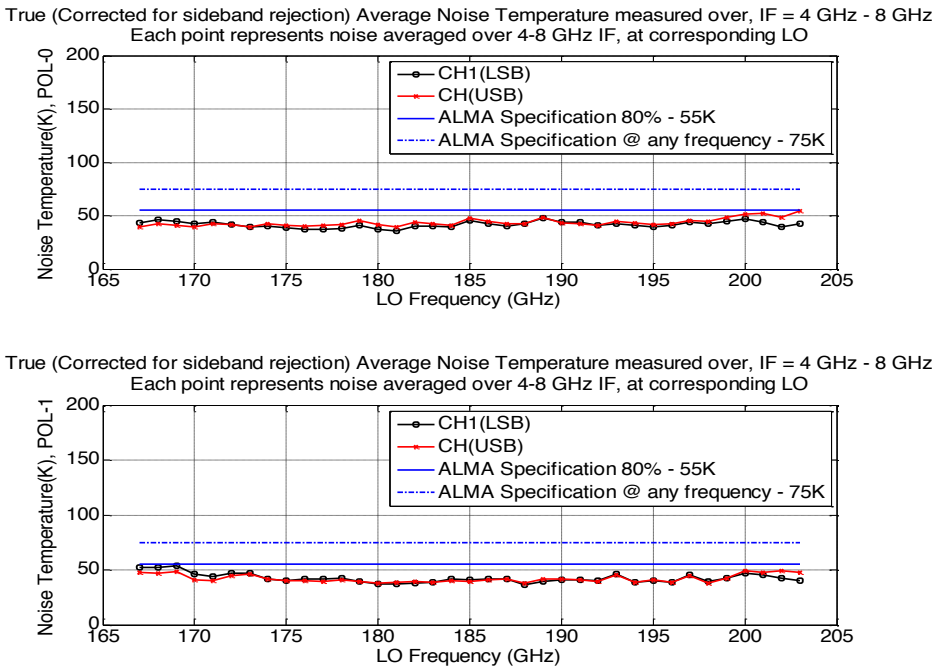



***Figure 20.*** *Typical noise performances of the two polarizations of an ALMA Band 5 receiver cartridge. All measurements performed by GARD.*

## 7.10 Local-tie of the Onsala 20 m telescope with GNSS

Geodesy data taken with the two gimbal-mounted GNSS antennas on the 20 m telescope were during 2014 analysed and a purely GPS-derived local tie was determined. The results show that both kinematic and semi-kinematic sessions give repeatabilities on the order of a couple of mm, which is sufficient for a local-tie monitoring. The 20 m telescope GNSS antennas were also operated throughout the 15-day long continuous VLBI campaign CONT14 in May 2014. At the same time a student team from the University of Applied Sciences in Hannover (Germany) visited the observatory to make a classical local-tie survey. Several reflectors were mounted on the elevation cabin of the 20 m telescope, and monitored continually during the whole CONT14 campaign. These measurements were complemented with further classical surveys in the small survey network between the 20 m telescope and the GNSS monument. To support these measurements, three holes were drilled in the radome foundation to allow a direct visual connection between survey markers inside and outside the radome. After the completion of the classical measurements, GPS measurements were performed on the network survey markers during several weeks. The analysis of the GPS measurements and the classical measurements, as well as the combination of the two data sets, is almost finalized and will result in a new local-tie determination.

## 7.11 Gravimeter laboratory

Since September 2014, tide solutions are prepared on a weekly basis and results made available on the SCG homepage (http://holt.oso.chalmers.se/hgs/SCG/toe/toe.html). The analysis includes the sea-level sensors at Onsala and ancillary data in the regression. The RMS of the residual is typically below 8 nm/s$^2$. The OSO gravimetry laboratory hosted an absolute gravimeter campaign in May 2014, when two FG5 instruments operated in parallel (from Lantmäteriet in Gävle and from Leibniz University, Hannover, Germany). The campaign served three purposes: re-measuring gravity as a joint effort coordinated by the Nordic Geodetic Commission, calibration of the SCG, and finally inter-comparison of the absolute instruments to determine instrument-specific errors, e.g., offsets, variances, and orientation-dependent biases.

## 7.12 Super-tide-gauge station

The super-tide-gauge station, mentioned in last year's report, has been constructed in collaboration with the Swedish Meteorological and Hydrological Institute (SMHI). The permission to build the installation was obtained from the Kungsbacka municipality in February 2014. Figure 21 shows the station at the end of 2014. Test measurements are for the moment using four pneumatic bubbler tide-gauge sensors and one radar sensor. All of these sensors have a specified accuracy of approximately ± 3 mm over the measurement range. In the spring of 2014 a student team of the University of Applied Sciences in Hannover (Germany) visited Onsala and made a survey of the tide gauge instrumentation. During that visit the precise height relations between the various geodetic monuments were determined.

## 7.13 Investigations for a possible future DORIS station at Onsala

The situation has not changed since last year's report. There are uncertainties due to possible interference problems of Doppler Orbiography and Radiopositioning Integrated by Satellite (DORIS) stations in the vicinity of radio astronomical telescopes. No final conclusions or

recommendations have yet been reached in the geodetic VLBI community, so the project still has a low priority.

***Figure 21***. *Photograph of the new super tide gauge developed in collaboration with SMHI, which is now acquiring its first test observations.The tide gauge contains an inner plastic which is thermally insulated so that it always has an ice-free water surface. This insulation is protected from the environment by the outer concrete rings.*

### 7.14 Aeronomy station

The side-band responses of the double sideband 110 – 115 GHz system were measured and the LO-chain was optimized during spring 2014. The window of this radiometer was replaced during 2014 after test measurements were made on different window materials. A 0.1 mm PTFE (Gore Tex) film, with negligible attenuation at 3 mm wavelengths was finally chosen. The zenith brightness temperatures at 21 and 31 GHz from respectively the Astrid and Konrad radiometers are now used to estimate the zenith brightness temperatures at 22, 111 and 115 GHz. These brightness temperatures are then used for calibration purposes in the processing of the aeronomy data.

## 8 SKA Design Activities

OSO has continued and expanded its technical involvement in the Square Kilometre Array (SKA), an international project to build the world's next generation metre and centimeter wave radio interferometer. Since June 2012 Chalmers/OSO represents Sweden in the SKA Organisation Ltd, a British company that will lead the SKA project during its pre-construction/final-design phase through to the end of 2016. At the end of 2012 OSO obtained a VR planning grant to support SKA design work in 2013 and 2014. This grant has been used in 2014 to finance the involvement of staff at OSO and from the Chalmers' antenna group in SKA design studies. At the end of 2014 OSO obtained from VR a new planning grant to support SKA design work in 2015 and 2016.

The SKA1 design stage is planned to run for three years (2014–2016) and deliver final blueprints for building SKA Phase 1. OSO is involved in two international design consortia

within this process. The first of these is the SKA Dish Consortium (SKADC), formed by a number of institutions and companies across Europe, South Africa, Australia, China, and Canada. Within SKADC OSO is responsible for the design and prototype fabrication of a feed and receiver package for SKA Band 1 covering 350 – 1050 MHz. OSO/Chalmers is the lead institution within the second consortium (Wide-Band Single Pixel Feeds or WBSPF). WBSPF aims to deliver for the SKA Advanced Instrumentation Program (AIP) extremely wideband single pixel feeds. OSO has the overall project management role in this consortium, which, in addition to OSO/Chalmers, involves research institutions from China, Germany, Netherlands and France. Within WBSPF OSO/Chalmers is also technically responsible for the cryogenic integration, feed tests and delivery of the LNA package for the 4.6 – 24 GHz frequency range. Both the SKADC and WBSPF projects also involve researchers from the Chalmers Antenna Group, within the Signals and Systems Department (contributing 0.8 FTEs in total), and also manpower from Omnisys Instruments AB (0.5 FTEs). OSO collaborates also closely with staff from the Chalmers Microelectronics Laboratory on low noise amplifier design and prototyping within the WBSPF. At the end of 2014, OSO started negotiations with RUAG Space for their possible involvement in SKADC.

***Figure 22:*** *Picture of the Eleven Feed prototype for SKA Band 1 with people involved in its design and assembly.*

The work within SKADC was concentrated on studying the suggested feed alternatives (Quad-Ridged Feed Horn and Eleven Feed) within different reflector optics configurations. This work was presented at a Conceptual Design Review (CoDR) meeting in Sydney, Australia. During the second half of 2014 the detailed comparison of the two feed alternatives was carried out. In order to evaluate the performance of the feeds, prototypes were manufactured and tested. Figure 22 shows the manufactured Eleven Feed prototype. In a formal selection process run together with the SKA Organisation, the Quad-Ridged Feed Horn was selected as the final technical approach for Band 1. Prototype design of the complete feed-cryostat package was carried out during the last quarter of 2014, and the required data pack for the dish Production Design Review (PDR) was submitted as part of the documentation for the formal PDR meeting in early 2015.

Within WBSPF, OSO has carried out coordination and management work to keep the deliverables up to the schedule. A consortium face-to-face meeting, with more than 35 participants present, was organized in March in Onsala. During the year we have also negotiated the entry a new consortium member to the WBSPF project, namely the research group from Bordeaux Observatory France, who are experts in digital samplers (this group delivered the digital samplers for ALMA) who will deliver a wideband digital receiver prototype to the project. Work on a concept feed design for 4.6 – 24 GHz started in the second quarter of 2014.

## 9 Twin-Telescope System for Geodetic VLBI at Onsala

OSO obtained funding in 2011 from the Knut and Alice Wallenberg (KAW) foundation to build a new generation double-telescope for geodetic VLBI (the so-called Onsala twin telescopes or OTT). These twin telescopes (parabolic dishes with diameter 13 m) will follow the new geodetic VGOS standard and will enable position measurements with a precision 10 times better than existing geodetic VLBI observations. This improved accuracy opens up the possibility of discovering - and understanding - new global geodynamic effects. The new OTT ensures Onsala's position as a prominent geodetic fundamental station worldwide and secures its contribution to the Earth sciences, which in turn benefit sustainable social development. Although the grant of 30 Mkr to build the OTT was awarded by KAW in 2011 issues concerning obtaining various planning permits have delayed the implementation of the project. As reported in last year's annual report an updated application was submitted to Kungsbacka municipality to grant exemption from the law for shoreline protection in December 2013. The application was approved in February 2014, and within a couple of weeks we received news of approval by the authorities of the County of Halland. The telescope procurement process was started immediately thereafter and the tenders were received by mid-July. Thereafter, followed an evaluation period including the process of requesting several clarifications from the tender companies. Finally in December the contract for the two telescopes was formally awarded to MT Mechatronics and was signed by the parties just before Christmas 2014. Site preparations for the OTT have been going on during 2014. Figure 23 shows the status as of November. The telescope foundations will be constructed during 2015 and the telescopes will be delivered in the summer of 2016. Receivers, data handling and transmission systems will thereafter be built and installed. The first VLBI test observations arr expected during 2017. The complete twin telescope system is expected to be fully operational by the end of 2019

***Figure 23.*** *Preparations for the geodetic VLBI twin telescope, OTT. This photograph shows the site of the northern telescope. The site of the southern telescope is just outside this photo, to the right*

## 10 Replacement of the Onsala 20 m Telescope Radome

One of the most dramatic events of 2014 at the observatory was the replacement of the radome for the 20 m telescope (see Fig. 24 for a picture of the radome cap replacement). The old radome was installed at the same time as the 20 m telescope was erected almost 40 years ago, in 1975, by an American company ESSCO. The radome's function is to protect the telescope from the weather and from solar radiation. It has survived well over its guaranteed lifetime due to the overpressure inside the radome, which has smoothed the vibrations of the panels, and the careful maintenance over the years (yearly inspections during the last decades). Nevertheless, the material of the radome had deteriorated to the extent that the installation of a new one was unavoidable and for several years a replacement was planned. The only reasonable solution was to buy a new radome identical to the old one from ESSCO and to have it installed by the same company. After discussions with the company it was agreed on an installation procedure where a top cap consisting of 50 panels is changed in one go (see Fig. 24) and the remaining 570 panels were changed one by one. This procedure limited the time when the telescope was exposed to open air to a minimum. The installation started on 11$^{th}$ Aug. 2014 and was finished at the end of September. The new radome now has slightly better transmission properties for radio waves than the original one installed in 1975, and significantly better transmission than the aged radome it replaced; the new radome will also dry up much faster after rain. The new radome is expected to protect the telescope from the elements for decades to come.

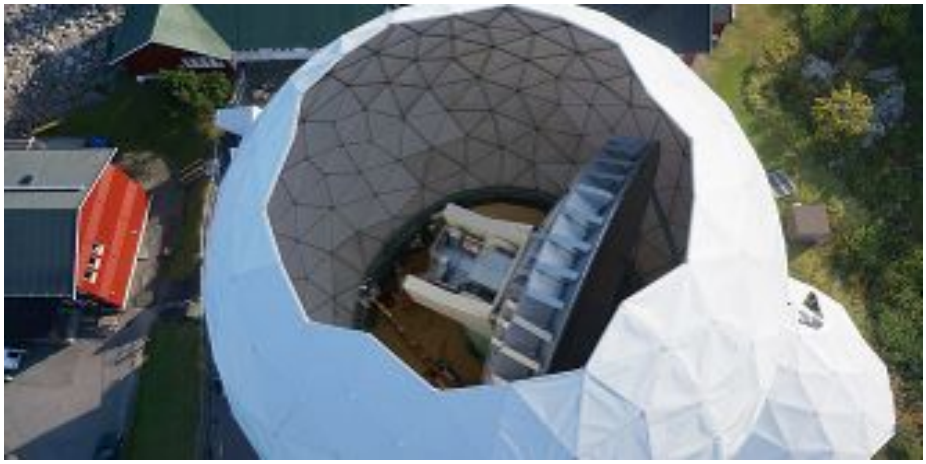


***Figure 24.*** *The top cap removed from the 20 m telescope radome.*

## 11 Memberships of International Committees

During 2014, 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. Michael Lindqvist is chairman of the Technical Operations Group (TOG) and member of the Observing Programme Committee).
- *The Joint Institute for VLBI in Europe (JIVE),* a Dutch foundation 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, and Per Bergman is the Swedish project scientist).
- *The International LOFAR Telescope (ILT)* Board, which oversees the operation of the ILT (the Director is a board member).
- *RadioNet3,* an EU-financed $I^3$ project, which coordinates all of Europe's leading radio astronomy facilities (The Director is a board member, Michael Lindqvist represents the EVN TOG and CRAF)
- *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 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)
- *Nordic Geodetic Commission (NKG)* through the working group on infrastructure (Rüdiger Haas is committee member)
- *The European VLBI Group for Geodesy and Astrometry (EVGA*) (Rüdiger Haas is chair person)
- *Global Geodetic Observing System (GGOS) Inter Agency Committee (GIAC)* (Rüdiger Haas is committee member)
- *ESF Committee on Radio Astronomy Frequencies (CRAF)* for the protection of the radio band for radio astronomical use (Michael Lindqvist is committee member)

## 12 RadioNet3 EU Project

The EU-funded RadioNet3 project (Advanced Radio Astronomy in Europe) began in 2012 and continued through 2014. In total RadioNet3 covers the period 2012 – 2015 and is a EU Integrated-Infrastructure-Initiative-funded network of all the major radio astronomical observatories in Europe (and some beyond). RadioNet3 follows on from a number of successful similar activities over the years. Its aim is to support the use of the radio astronomical facilities as well as to support R&D on new radio astronomical instrumentation and methods. From this activity OSO gets TransNational Access (TNA) funding for its operation of APEX and its contribution to astronomical VLBI. It also takes part in two Joint Research Activities: (Developments in VLBI Astronomy) and AETHER (Advanced European TeraHertz Heterodyne Receivers), described respectively in Sects 6.1 and 6.3.

## 13 Workshops, Schools, etc.

On Aug. 13-21 the Nordic ALMA node at OSO and the Dark Cosmology Center in Copenhagen (DARK) jointly organized the school “Introduction to sub-mm interferometry and science with ALMA”. The course, held at DARK, gave an introduction to interferometric observations, data reduction, and analysis with a focus on ALMA observations. Lectures on theory of interferometry were complemented with practical exercises and science presentations. A total of 17 master students, PhD students, and postdocs from all the Nordic countries participated. OSO was host for the RadioNet3 Technical Workshop on Metrology at Radio Astronomy Antennas, Sep. 1-2, 2014.

## 14 Education

The OSO staff does not generally take part in the academic teaching at Chalmers (except for 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 are used in astronomy courses, the 25 m telescope in a satellite-communication course, GNSS equipment in a satellite-positioning course, the superconducting gravimeter in a bachelor thesis project, and laboratory equipment in courses on microwave, millimetre wave, and THz technology. Additionally, during the year students from the universities in Stockholm and Lund visited the Observatory to carry out observations and/or to learn about radio astronomy.

## 15 Outreach

Outreach activities to children and the general public are important missions of OSO. Outreach at Onsala is led and coordinated by a half time position (0.5 FTE) employed by OSO, but it also uses manpower resources (0.9 FTE) bought in from the PhD students of the Radio Astronomy group at Chalmers (this effort is funded by the Chalmers financial contribution to OSO). Outreach encompasses a wide range of tasks including site visits, talks, and media interaction.

In 2014, almost 1700 people visited the Onsala site, its telescopes and exhibition. Visitors took part in 52 guided tours, most of them consisting of school students in all age groups. About 300 visitors came by chartered buses during two open days (during the Science Festival in April, and on Mothers' Day in May).

A program has been started aimed at improving access for schools to the observatory and to Chalmers scientists. Using funds from the Chalmers University of Technology Foundation, optical lab equipment has been bought and used both during our visits to schools and for school students visiting the Observatory. Students came to the Observatory for their work experience week (PRAO; two students in November), and three high school students carried out projects on the Milky Way using the SALSA radio telescopes. SALSA was also upgraded with both new hardware and new software to make the telescopes more user-friendly, more reliable, and to allow a wider variety of projects. Many school classes and amateur astronomers connected remotely: SALSA was booked by 50 users for an average of 23 hours every week, most of them in Sweden but also from as far away as Madeira and Honduras.

OSO has also initiated a closer collaboration with local science outreach projects. During the Gothenburg Science Festival in April, OSO co-organised a day of talks and hands-on activities at the city observatory in Slottsskogen park which attracted around 150 visitors. During Sweden's Day and Night of Astronomy in October our regular star party "Onsala stjärnträff" was complemented with a family-oriented Big Bang Day in collaboration with the Young Academy of Sweden at science centre Universeum in Gothenburg. Work to help Universeum upgrade their space exhibition was started. OSO joined and supported the new

initiative Science Safari, which has secured funding from the Halland region for a mobile science center.

By press releases, social media and direct contact with reporters, OSO communicated news on the upgrade of the Onsala 20 m telescope's radome, about progress developing broadband feeds for the SK and the observatory's innovative GNSS tide gauge, leading to newspaper articles and several appearances on regional television. Staff handled many media enquiries on astronomical topics and was regularly quoted in news media.

OSO represents Sweden in the SKA's communication network, one new result of which is the SKA project's website in Swedish, http://sweden.skatelescope.org. Likewise, OSO has a new website (in Swedish and English) as of 2014, http://www.chalmers.se/en/centres/oso/Pages/default.aspx.

## 16 Changes in Organisation

A new chairman of the OSO Steering Committee, Kjell Möller, was appointed by Chalmers in consultation with VR to begin a 3-year term on Jan. 1st 2014. Chalmers and VR have also re-appointed the existing members of the OSO Steering Committee for a new three-year term starting Jan. 1st 2014. A new OSO Time Allocation Committee started its 3-year term on Oct. 19th 2013. 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.

During 2014, international negotiations between several European Research Councils were successfully concluded to convert the Joint Institute of VLBI in Europe (JIVE) in the Netherlands (which runs the EVN correlator) from a Dutch foundation into a European Research Infrastructure Consortium (ERIC). The new organisation is called the **JIV-ERIC** and will start to operate from Jan. 1st 2015, taking over as the successor organisation to JIVE. VR is a founding member of the JIV-ERIC and appoints two members to the council, these two members will be Catarina Sahlberg from VR and John Conway from OSO.

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

## 18 Importance to Industry

The activities at OSO are not directly aimed at industry-relevant products. Their importance lies rather in the spin-off products, in particular in microwave engineering, and in

collaborations with local high-tech companies, such as Omnisys Instruments A, Low Noise Factory and RUAG. The work on a cryogenic broadband feed system based on the 11-feed, which for OSO has relevance for both geodetic VLBI and the SKA, has lead to the formation of a spin-off company, and Omnisys develops a cryogenic broadband feed system specifically for geodetic VLBI based on the design developed together with OSO. Because of the large scale of the SKA project it is expected that this will have a large financial payback to Swedish industry especially if Sweden fully joins the SKA construction phase. OSO staff also contributes to 'continuing professional development' of relevance to industry.

## 19 Financial Account

OSO gets most of its operation funding from the Research Council (VR) and Chalmers. There is in addition a small contribution to operations funding within the EU-financed RadioNet3 project via its Trans National Access (TNA) element, which supports international access to APEX and the use of the OSO telescopes in EVN VLBI. The income and expenditure on the VR account for 2014 are as follows:

| | |
|---|---|
| *VR income, operation* | *38 000* kkr |
| *Expenditures on VR grant:* | |
| Salaries | 20 746 kkr |
| APEX central operation | 5 898 kkr |
| LOFAR, central operation | 811 kkr |
| JIVE, central operation | 1 266 kkr |
| SKA, membership fee | 2 177 kkr |
| ESF, Frequency manager | 171 kkr |
| Data fibre links to Stockholm/Netherlands | 484 kkr |
| Travel | 769 kkr |
| Equipment | 5 147 kkr |
| Supplies | 2 180 kkr |
| Services | 867 kkr |
| Buildings | 68 kkr |
| Total | 40 582 kkr |
| *Chalmers income, operation* | *18 343* kkr |

*Project funding*

In addition to its operations funding the Observatory is involved in a number of multi-year projects, the total values and periods of these projects are given below.

| | |
|---|---|
| VR Planning Grant (SKA) 2013–2014 | 6 600 kkr |
| Chalmers, EU support | 435 kkr |
| KAW, Onsala Twin-telescope System 2014-2018 | 29 700 kkr |
| EU, RadioNet3, 2012 – 2015 | 704 k€ |
| ESO ALMA Band 5, 2013 – 2017 | 41 074 kkr |

## Acronyms

| | |
|---|---|
| AETHER | Advanced European TeraHerz Heterodyne Receivers |
| ALMA | Atacama Large Millimeter/submillimeter Array (Chile) |
| ARC | ALMA Regional Centre |
| APEX | Atacama Pathfinder Experiment (Chile) |
| DBBC | Digital Base Band Converter |
| DIVA | Developments In VLBI Astronomy |
| eMERLIN | upgraded Multi-Element Radio Linked Interferometer Network (UK) |
| ESO | European Southern Observatory |
| EVN | European VLBI Network |
| FFTS | Fast-Fourier-Transform Spectrometer |
| FTE | Full Time Equivalent |
| GARD | Group for Advanced Receiver Development |
| GGOS | Global Geodetic Observing System |
| GGP | Global Geodynamic Project |
| GIAC | GGOS Inter Agency Committee |
| GLONASS | Global Navigation Satellite System (translated from Russian) |
| GMVA | Global Millimetre VLBI Array |
| GPS | Global Positioning System |
| GNSS | Global Navigational Satellite Systems |
| HEB | Hot Electron Bolometer |
| IAG | International Association of Geodesy |
| ILT | International LOFAR Telescope |
| IGS | International GNSS Service |
| IRAM | Institut de Radioastronomie Millimetrique |
| IVS | International VLBI Service for Geodesy and Astrometry |
| ITRF | International Terrestrial Reference Frame |
| JIVE | Joint Institute for VLBI in Europe (NL) |
| KAW | Knut and Alice Wallenberg foundation |
| LOFAR | Low Frequency Array |
| LNA | Low Noise Amplifier |
| NKG | Nordic Geodetic Commission |
| NOVA | Netherlands Research School for Astronomy |
| MMIC | Monolithic Microwave Integrated Circuit |
| NRAO | National Radio Astronomy Observatory (USA) |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| OSO | Onsala Space Observatory |
| RadioNet3 | Advanced Radio Astronomy in Europe |
| SALSA | Such a Lovely Small Antenna |
| SEST | Swedish-ESO Submillimetre Telescope (Chile) |
| SHFI | Swedish Heterodyne Facility Instrument for APEX |
| SIS | Superconductor-Insulator-Superconductor (receiver technology) |
| SKA | Square Kilometre Array |
| SKADC | SKA Dish Consortium |
| SNSN | Svenska nationella seismiska nätverket |
| SWEPOS | Lantmäteriets stödsystem för satellitpositionering i Sverige |
| TAC | Time Allocation Committee |
| TNA | Trans National Access |
| ToO | Target of Opportunity |
| VLBA | Very Large Baseline Array (US) |
| VLBI | Very Long Baseline Interferometry |

| | |
|---|---|
| VGOS | VLBI2010 Geodetic Observing System |
| WBSPF | Wideband Single Pixel Feed Consortium |
| WVR | Water Vapour Radiometer |