ONSALA RYMDOBSERVATORIUM
CHALMERS TEKNISKA HÖGSKOLA

ONSALA SPACE OBSERVATORY
CHALMERS UNIVERSITY OF TECHNOLOGY

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Report on the activities at Onsala Space Observatory during 2011

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Operations

During 2011 Onsala Space Observatory (OSO) operated the following facilities:

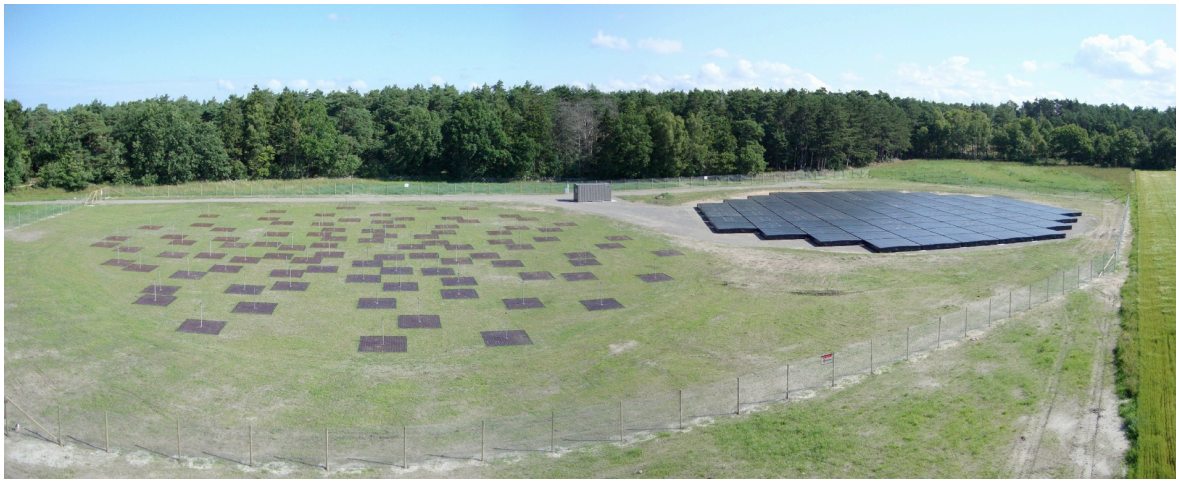
- The Onsala 20 m telescope for astronomical Very Long Baseline Interferometry (VLBI), geodetic VLBI, and single-dish astronomy
- The Onsala 25 m telescope for astronomical VLBI
- The Onsala LOFAR station for the International LOFAR Telescope
- The APEX telescope for single-dish astronomy
- The Nordic ARC node (the Atacama Large Millimeter/submillimeter Array Regional Centre node)
- The Onsala aeronomy station for observations of atmospheric H_2O, CO, and O_3, and two water vapour radiometers (WVRs) to support space geodesy
- The Onsala gravimeter laboratory for absolute and relative gravimeters
- The Onsala GNSS station
- The Onsala time & frequency laboratory

In general, they have operated without any major problems during the year. The astronomical observations are scheduled based on recommendations from time allocation committees. The geodetic VLBI observations are scheduled by the International VLBI Service for Astrometry and Geodesy (IVS). The other instruments deliver data through data archives.

The activities at the major facilities were distributed in the following way (in round terms):

- The Onsala 20 m telescope: 70 days of single-dish astronomy
  25 days of astronomical VLBI
  40 days of geodetic VLBI (including CONT11)
- The Onsala 25 m telescope: 65 days of astronomical VLBI
- The LOFAR station was taken into operation in early October
- APEX telescope 50 days of single-dish astronomy

Time for technical service, pointing, radome maintenance, etc. is not included, and amounts to about 35 and 25 days on the 20 m and 25 m telescopes, respectively. In addition to this, considerable time is devoted to data quality checks, developments and tests, etc.. A major undertaking was the successful installation and commissioning of the LOFAR station, which was inaugurated on Sept. 26.



The Onsala LOFAR station installed, commissioned, and inaugurated during the year. It consists of two dipole arrays and digital electronics for signal processing. The data is sent on high-speed data link to Groningen (NL).

For the other facilities the activities are summarised as:

- The Nordic ARC node has provided support to the Nordic and Baltic ALMA user communities during this year when ALMA was opened for early science (Cycle 0 call for proposals). It organized the Nordic ALMA Cycle 0 proposal preparation workshop (18/19 May), worked on ALMA Science Verification data reduction, and CASA and Observing Tool testing, and gave presentations about ALMA and millimetre astronomy at Nordforsk Nordic graduate school 'Young Stars across Time and Wavelengths' in Turku, Finland, 6-16th June.
- The Onsala aeronomy station was moved to a new hut during the year. The WVR Astrid was operated through the year, while the WVR Konrad went through a major upgrade.

- The superconducting gravimeter was in continuous operation during the year in the gravimeter laboratory. There were two visits by absolute gravimeters (Lantmäteriet and Leibniz IfE).
- A tide gauge based on the GNSS technique was installed.
- The time & frequency laboratory hosts the hydrogen maser, which is necessary for VLBI observations. It also collaborates with the SP Technical Research Institute of Sweden on a Swedish time-keeping system using a second hydrogen maser and cesium clock.

R&D

The sixth, and final, ALMA Band 5 cartridge, within the EU-financed ALMA Enhancement Programme, was delivered by the Group for Advanced Receiver Development (GARD) to the ALMA project. This has been a major undertaking for OSO, which was now successfully concluded. Four partners, the European Southern Observatory (ESO), the Netherlands Research School for Astronomy (NOVA), OSO, and the Rutherford Appleton Laboratory (RAL) are working on a proposal to equip all ALMA telescopes with Band 5 cartridges within the ALMA Development Programme. If successful this means that GARD will provide selected components and technical expertise.

There are three principle achievements by GARD within the AMSTAR+ project. GARD fabricated and characterized all-metal waveguide components (coupler, divider) for the 345 – 500 GHz frequency band, with state-of-the-art performance. It performed the surface quality assessment of the waveguide circuits of a prototype ALMA band 9 sideband-separating mixer block in collaboration with SRON in the Netherlands. Finally, it demonstrated experimentally a technology aiming at the realization of a balanced HEB mixer (1.6 – 2 THz), using an innovative self-aligning chip design compatible with waveguide split-block technology. This demonstrator opens the way for a realization of multi-pixel THz waveguide receivers.

The development of a new 3 mm heterodyne receiver for the Onsala 20 m telescope, based on experience from the APEX and ALMA receivers, is ongoing in collaboration between GARD and the Electronics Lab.. In the first step a single-polarisation sideband-separating receiver has been tested in the laboratory.

Work continued on developing the ultra-wideband eleven-feed design for both geodetic VLBI use and for the Square Kilometre Array (SKA), the latter work was carried out as part of a contract with the SKA Project Development Office. The SKA version of the feed was designed to work above 1.2 GHz with a final goal of optimising sensitivity in the range 1.2 – 4 GHz. Versions of the feed with bent edges and with a new circular geometry were both designed and constructed. Electronic feeding circuits for interfacing the feed to different types of wide-band low noise amplifiers were developed. A complete system model incorporating EM modelling of the feed and noise/gain/matching of receiver components was created, the predicted final noise performance versus frequency closely matched the results of on-sky measurements made at Onsala. The geodetic VLBI version of the feed (covering 2 – 14 GHz) was further developed in collaboration with the Omnisys AB company in Gothenburg.

Further SKA-related work concerns evaluating the performance of SKA offset and symmetric dishes, including the effects of different feed designs. The resulting simulations allowed estimates of total sensitivity performance to be made including spillover (pickup of noise from the ground). The work on symmetric dishes was

incorporated into a design document for the European dish consortium submitted to the SKA dish design review held in Calgary in July. Work on the instrumental polarisation specifications of SKA and the accuracy of pulsar timing (a major SKA astrophysical goal for detecting gravity waves and testing the equation of state of neutron stars) is ongoing. This specification included the effects of calibration of polarisation impurities using calibration on astronomical sources. In addition, work on estimating the impact of dish electromagnetic total intensity and polarisation properties on achievable imaging dynamic range, again after incorporating astronomical calibration, is ongoing.

A more accurate antenna element beam model for LOFAR without singularities at the zenith and properly taking into account parallactic angle rotation has been developed. This model was incorporated into the LOFAR data processing pipeline. For application to the international baselines of LOFAR, work has started on developing software for converting linear polarisation to circular (incorporating geometry effects), a conversion which has advantages for long baselines given the differential Faraday rotation and large ionosphere-induced delays.

User statistics

Here 'user' means an author or co-author of a proposal granted observing time during 2011. It is far from straightforward to define 'user groups' and to give the number of new user groups. Therefore we give the number of individual users instead:

- Onsala 20 m telescope, single-dish: 31
  (7 had Swedish affiliation, 8 had not used the telescope before; the oversubscription rate was 1.0)

- APEX telescope (Swedish time), single dish: 187
  (24 had Swedish affiliation, 87 had not used APEX before on Swedish time; the oversubscription rate was 1.5)

- Astronomical VLBI: 204
  (The handling of proposals, scheduling, etc. is done centrally, mainly through EVN, and OSO does not have direct access to all statistics, etc. But we have been informed that in 2011, there were 204 individual users of EVN. Most EVN projects included at least one of the Onsala telescopes. The oversubscription rate was 2.7)

- Geodetic VLBI: Observations are performed as a service to the global geodesy community, i.e., the observations are not performed for particular scientific projects. Thus, it is not possible to give the number of users. It can be noted though, that 11 refereed publications with a total of 46 individual authors (2 had Swedish affiliation) were based on geodetic VLBI data including the Onsala 20 m telescope.

- The Onsala aeronomy station data were delivered through the Network for the Detection of Atmospheric Composition Change (NDACC).

- The Onsala gravimeter laboratory data was delivered via the Global Geodynamics Project (GGP), and there were two visits by absolute gravimeters.

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

Peer-reviewed papers

Only publications in refereed journals based on the OSO instruments are included (the numbers are minimum, publications may have been missed).

– Onsala 20 m telescope, single-dish:	5	
– APEX, single-dish:	48	(Swedish, ESO and MPI time)
– Astronomical VLBI:	17	
– Odin astronomy	2	
– Geodetic VLBI:	11	
– GNSS:	3	
– Odin aeronomy:	5	

In addition, there are 9 refereed publications based on R&D within mm/sub-mm instrumentation, broadband receiver systems, antenna-feed system simulation, and SKA performance.

Selected scientific highlights

The first detection of hydrogen peroxide (H_2O_2) molecules in interstellar space was made with APEX, using the SHFI receiver built by GARD. Hydrogen peroxide is a key molecule in astrochemistry. The detection of hydrogen peroxide, in a dense cloud of gas and dust close to the star Rho Ophiuchi about 400 light-years away, will help astronomers to better understand the formation of water and oxygen molecules in the Universe. (Bergman et al., A&A 531, L8)

Observational tests of suggested formation mechanisms for interstellar methanol have been made with the Onsala 20 m telescope, through observations of gas associated with young stellar objects. Two independent observational tests were conducted, one showing consistency with methanol formation from hydrogenation of CO on grain surfaces, and the other being inconclusive. (Wirström et al., A&A 533, A24)

Several observations have been made with APEX of deuterated molecules, e.g., deuterated formaldehyde in rho Ophiuchi A (Bergman et al., A&A 527, A39), D_2H^+ in a pre-stellar core (Parise et al., A&A526, A31), water deuterium fractionation in the low-mass protostar NGC1333-IRAS2A (Liu et al., A&A 527, A19), and deuterium fractionation and the degree of ionisation in massive clumps within infrared dark clouds (Miettinen et al., A&A 534, A134).

Observations with APEX have been important for the Herschel Space Observatory (HSO). Emission lines from circumstellar envelopes observed with APEX were used as external calibrators in evaluations of the in-orbit performance of the HIFI instrument onboard the HSO (Roelfsema et al., A&A 537, A17).

VLBI observations of 17 compact radio continuum sources in the nearby ultra-luminous infrared galaxy Arp220 show that they are a mixture of supernovae (SNe) and supernova remnants. Seven previously unknown SNe were detected, the largest number of SNe ever observed simultaneously in the same galaxy. (Batejat et al., ApJ 740, 95)

The highest-redshift radio quasar known at present, J1429+5447 (at a redshift, z, of 6.21), was observed with VLBI. Its observed radio properties, the compact but somewhat resolved structure on linear scales of < 100 pc, and the steep spectrum, are similar to those of two other $z \approx 6$ radio-loud quasars. Whether compact steep-spectrum radio emission is a rule or an exception is not known; a larger sample of extremely distant radio-loud AGNs needs to be observed in the future. (Frey et al., A&A 531, L5)

The LABOCA receiver on APEX was used to carry out a sub-mm survey of five clusters of galaxies. The clusters act as gravitational lenses and magnify background sources. In the survey, 37 sub-mm sources were discovered, out of which 14 were new detections. Such sub-mm galaxies are a population of dusty star-forming galaxies at high redshift. Measuring their properties will help relate them to other types of galaxies, both at high and low redshift. (Johansson et al., A&A 527, A117)

Observations with APEX of CII and CO in the $z = 4.76$ sub-mm galaxy LESS J033229.4-275619 suggest that the highest-redshift star-forming galaxies may also be characterised by lower metallicities. (De Breuck et al., A&A 530, L8)

The gravitational deformations of radio telescopes used for geodetic VLBI lead to systematic height and scale errors in the VLBI results. A model to correct for the effect, derived using classical geodetic measurements to determine the telescope geometry, was developed. (Sarti et al., Journal of Geodesy, 85(1), 1)

A new and improved version of the ITRF (International Terrestrial Reference Frame) has been presented. The new ITRF2008 uses more accurate information on the local tie vectors between the reference points of the different space geodetic techniques at fundamental stations, and is more consistent with the space geodetic techniques than previous ITRF versions. (Altamimi et al., Journal of Geodesy, 85(8) 457)

Onsala and Tsukuba observed the whole CONT11 campaign as a 15-days-long 'ultra-rapid' session where the Earth rotation angle was determined in near real-time. This was the first time this has been made over such a large time interval, and it can be seen as a pilot study for VLBI2010, i.e., the next generation VLBI network and observations.

A more than three months long GNSS tide-gauge time series with measurements at Onsala was analysed, and the amplitudes and phases of ocean tides were determined and compared to predictions based on global ocean models. The results show that the global ocean models have a limited accuracy in Kattegatt, and there is a need to complement the global models with refined regional models. (Löfgren et al., Radio Sci., 46, RS0C05)

The superconducting gravimeter has proven to be very useful for long periodic seismology. The Earth's free oscillations after the Sendai earthquake in March 2011 were observed clearly and over a long time period.

International collaborations

OSO was involved in the following international collaborations in 2011:

– The European VLBI Network (EVN) for astronomical VLBI (Hans Olofsson is

board member; Michael Lindqvist chairman of the Technical Operations Group 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 (Hans Olofsson is board member)
- The APEX project where three partners operate a 12 m sub-mm telescope in northern Chile (Hans Olofsson and Per Bergman are board members)
- The International LOFAR Telescope (ILT) Board, which sets up the roles for the operation of the ILT (John Conway is board member)
- NEXPReS, an EU-financed project which promotes the use of eVLBI (John Conway is board member)
- RadioNet, an EU-financed I^3 project, which coordinates all of Europe's leading radio astronomy facilities (Hans Olofsson is board member)
- PrepSKA, an EU-financed preparatory phase project for the SKA (Hans Olofsson is board member)
- European SKA Consortium, which promotes the European involvement in the SKA project (Hans Olofsson is committee member)
- The SKA Founding Board, representing VR which as observer status
- International VLBI Service (IVS), which operates geodetic VLBI (Rüdiger Haas is board member)
- International Earth Rotation and Reference Frame Service (IERS) (Rüdiger Haas is committee member)
- GGOS Inter Agency Committee (GIAC) (Hans Olofsson is committee member)
- Nordic Geodetic Commission (NKG) through the working group on infrastructure (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)

Outreach

Over 2000 people visited the Onsala site, its telescopes and exhibition in 2011. Around 250 of them came to our biggest events of the year, the inauguration of the new LOFAR station and the Swedish Astronomers' Days conference. In total 1750 visitors took part in 65 guided tours, the largest number of which were school classes covering all age groups. Events were organised during the Gothenburg Science Festival, among them a public debate with the title 'From the Big Bang to the Robot Era' and a public talk about the future large observatories. Our staff gave a number of public talks about astronomy across the country. Staff members wrote a number of articles and reviews for the magazine Populär Astronomi, and contributed to a spread about LOFAR in Forskning & Framsteg.

Press interest in the department's activities increased in 2011. Journalists made a number of visits to the Onsala site, primarily to report about the new LOFAR station and its opening. The discovery of hydrogen peroxide in space with APEX was reported in a number of international sources. The discovery of seven supernovae in the same galaxy was covered in most of the Swedish news media and led to articles in both New Scientist and National Geographics. High school students from Sweden and elsewhere in Europe continue to use our SALSA radio telescopes to carry out school projects observing interstellar gas in the Milky Way. An updated version of the Onsala Space Observatory leaflet was printed, plus a new leaflet on earth science at Onsala, and a wall calendar for 2012 with photographs showing the observatory, its research and the big events of 2011.

Major changes in organisation

There were no major changes in the organisation during 2011. Chalmers University of Technology operates OSO, which forms a part of the Dept. of Earth and Space Sciences. The National Facility operates under a contract between the Research Council (VR) and Chalmers which outlines the conditions under which the National Facility should be operated, and gives the respective financial contributions until (and including) 2013. The internal organisation of OSO has not changed, except that this was the first full year with a deputy director, John Conway, joining the management.

A new Steering Committee had its first meeting during the year under its chairman Lars Leijonborg, former minister of education.

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 important 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 base for all navigational applications. The OSO staff and instruments are involved in education at all levels from bachelor to graduate studies at Chalmers, and through organised schools.

Importance to industry

None of the activities at OSO are directly aimed at industry-relevant products. Their importance lies rather in the spin-off products, in particular in microwave engineering, and in collaborations with high-tech companies, such as Omnisys Instruments AB (Gothenburg). The work on a cryogenic broadband feed system based on the eleven 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 together with OSO. OSO staff also contributes to 'continuing professional development' of relevance to industry.

Financial account

VR operation	34 370 kkr
Expenditures:	
Salaries	18 391 kkr
APEX, ESO invoice	5 225 kkr
APEX, liquid He	121 kkr
LOFAR, central operation	803 kkr
JIVE, central operation	1 257 kkr
ESF, Frequency manager	169 kkr
European SKA Consortium	227 kkr
Data fibre link, 10 Gb/s to Sthlm	613 kkr
LOFAR installation	3 218 kkr
Travel	1 079 kkr
Equipment	2 428 kkr
Material, etc	1 341 kkr
Outreach	140 kkr
Buildings	559 kkr
Telephones	213 kkr
Miscellaneous	705 kkr
Total	36 489 kkr
Chalmers operation	12 000 kkr
Other funding:	
EU, RadioNet, 2009 – 2011	4 420 kkr
EU, ALMA Band 5, 2006 – 2012	51 460 kkr
EU, NEXPReS, 2010 – 2013	2 650 kkr
VR, LOFAR station, 2008 – 2013	6 900 kkr
VR, Geodetic station, 2009 – 2011	3 510 kkr