



Application

2025-02-18

2025-00155	Chalmers tekniska högskola	FI-IP														
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Funds applied for <table> <tr> <td>Year:</td> <td>2026</td> <td>2027</td> <td>2028</td> <td>2029</td> <td>2030</td> <td>Total amount applied</td> </tr> <tr> <td>Amount:</td> <td>0</td> <td>52,151,000</td> <td>34,713,000</td> <td>37,350,000</td> <td>36,126,000</td> <td>160,340,000</td> </tr> </table>			Year:	2026	2027	2028	2029	2030	Total amount applied	Amount:	0	52,151,000	34,713,000	37,350,000	36,126,000	160,340,000
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Descriptive information

Name of infrastructure (Swedish)

Onsala rymdobservatorium

Name of infrastructure (English)

Onsala Space Observatory

Participating organisations

Chalmers University of Technology

Abstract (English)

The Onsala Space Observatory (OSO) infrastructure supports radio astronomy and space geodesy, two distinct disciplines sharing common observing techniques. OSO's VR-funded radio astronomy mission is to support Swedish astronomers' access to submillimetre to metre wavelengths. OSO delivers on this goal by operating its own telescopes and supporting Swedish use of major international radio telescopes. OSO's telescopes normally operate as part of continent/world-spanning networks to produce the sharpest astronomical images, making even the imaging of black holes possible. Supported international telescopes are primarily the Atacama Large Millimeter/Submillimeter Array (ALMA) in Chile and the Square Kilometre Array (SKA), currently being built in South Africa and in Australia. OSO has played a critical role in the construction of both ALMA and SKA, in the process bringing back large amounts of funding to both Swedish industry and academia. This proposal seeks funding so that OSO can enable transformational radio astronomy by (1) providing the observing and user support committed to international projects, (2) building new world-best receivers for OSO's telescopes, (3) delivering new state-of-the-art receivers for the ALMA upgrade (in return securing extremely valuable ALMA observing time for Swedish users), and (4) developing a large Swedish radio astronomy data processing node to handle the avalanche of data that will come from the upgraded ALMA and from the SKA.

Popular science description (Swedish)

Onsala rymdobservatorium (OSO) skapar möjligheter för forskare att förstå vårt universum och vår planet, genom att ge tillgång till toppmodern och innovativ teknik. Vi utvecklar och ger tillgång till teleskop och andra instrument som är känsliga för radiovågor – ljus med lång våglängd. Sverige får därmed tillgång till det osynliga universum, och till samhällskritiska mätningar av jordens alla rörelser. Dagens extremt dataintensiva radioastronomi driver dessutom innovation inom högaktuella teknikområden som trådlös teknik, positionering, maskininlärning och ai. Med stöd från Vetenskapsrådet säkrar Onsala rymdobservatorium svenska forskares tillgång till, inflytande över och deltagande i världens främsta internationella samarbeten inom radioastronomi. Teleskopen i Onsala ingår i globala nätverk som ger de skarpaste bilderna av universum, och som också gett oss de första bilderna av svarta hål.

Under åren som kommer vill vi framför allt säkra tillgång till och stöd till forskare inför två av världens allra största astronomiprojekt: SKAO-teleskopen som är under uppbyggnad i Sydafrika och Australien, och uppgraderingen av ALMA i Chile. OSO har spelat avgörande roller i uppbyggnaden av båda dessa. Svensk industri och svenska forskare har dessutom fått stor utdelning - ekonomiskt, tekniskt och kunskapsmässigt - från dessa projekt.

Nu vill vi uppfylla våra åtaganden inom dessa projekt och att ta del av dess stora möjligheter. Genom att utveckla nya mottagare i världsklass för teleskopen i Onsala möjliggör vi teknisk innovation på högsta nivå och fortsatt nyskapande utforskning av universum. Genom att utveckla nya mottagare för ALMA:s uppgradering får svenska astronomer direkt tillgång till eftertraktad observationstid. Och genom att bygga upp en svensk nod för databehandling positionerar vi Sverige inför lavinen av nya spännande data från ALMA och SKAO-teleskopen, och möjliggör upptäckter som kan förändra vår förståelse av universum.

Subsidiary focus

Infrastructure project

National infrastructure

Area/infrastructure

Onsala Space Observatory

State the number of years the application covers. If funding is applied for from 2027, for technical reasons the year 2026 must also be included in "Number of years", and 1 January 2026 will be set as the start date for the project. The amount applied for year 2026 is then set to 0 SEK.

Number of years

5

Below, state the actual start year and end year.

Actual start year

2027

Actual end year

2030

The goals of the infrastructure

Goals related to scientific output

Key **SG** - Science Goal, **SD** - Science Deliverable. Further details in Time Plan section.

Module 1 - Leadership

SG-1.1 - Leadership continuity and succession - Ensure continuity of OSO scientific and operational leadership in preparation for a new OSO Director in place during the next but one funding period 2031-2034.

- **SD-1.1-1** - Current Director distributes knowledge and leadership experience to deputy and other senior staff to allow for smooth succession/support of future OSO Director.

Module 2 - Onsala Telescopes

SG-2.1 - New 20 m telescope receivers - New Triband receiver enabling new black hole/jet launching science, CX band receiver to allow full co-observing compatibility with SKA.

-- **SD-2.1-1** - Deliver 20 m telescope Triband receiver.

-- **SD-2.2-2** - Deliver 20 m telescope CX band receiver.

Module 3- ALMA Receivers

SG-3.1 - Obtain extra science time on ALMA via delivery of band 7 receivers - OSO's GARD receiver group will deliver new Band 7 receivers to ALMA as part of its upgrade - in return generating valuable ALMA guaranteed observing time to Swedish astronomers.

-- **SD-3.1-1** - Pass ESO (customer) project gate of demonstrating a prototype ALMA Band 7 WSU compliant receiver cartridge and begin production of first 6 ALMA band 7 receiver cartridges.

-- **SD-3.1-2** - Pass ESO (customer) Manufacturing Readiness Review (MRR) gate, start process of procuring materials and ramping-up series production.

-- **SD-3.1-3** - Achieve full production rate of 2.5 cartridges per month.

SG-3.2 - Work for continued socioeconomic impact from radio astronomy via industrial involvement in ALMA (and future SKA) projects.

-- **SD-3.2-1** - Regular contacts with Big Science Sweden industrial liaison officer before ESO/SKAO council meetings.

-- **SD-3.2-2** - Work for permanent funding mechanism for technical developments toward Big Science facilities that generate large industrial return for Sweden.

Module 4- ALMA Regional Centre Node

SG-4.1 Position Swedish scientists to exploit new upgraded ALMA (Wide Band Sensitivity) capabilities - Prepare the Swedish user community to exploit new ALMA capabilities offered by its Wideband Sensitivity Upgrade (WSU).

-- **SD-4.1-1** End-to-end test of the new WSU capabilities during science commissioning and verification; including a full test run using the Nordic ARC node facilities.

-- **SD-4.1-2** Provide user support for the first Nordic ALMA WSU projects, both under general ALMA time and Band 7 Guaranteed Time Observing, see Module 3.

Module 5 - SKA Regional Centre Node

SG-5.1 Position Swedish scientists to exploit first Science data from SKA - Prepare the Swedish user community to fully exploit first SKA science data and take a full part in the forming international Key Science projects.

-- **SD-5.1-1** Organize 4th Sweden SKA days 27-Q2 - As part of series of national meetings every 18 months.

-- **SD-5.1-2** Organize workshop on exploiting Swedish SRC node resources for analysing SKA data.

Goals related to the development of the infrastructure

Key **DG** - Development Goal, **DD** - Development Deliverable. Further details in Timel Plan section.

Module 1 - Leadership

DG-1.1 - Support frequency protection efforts

-- **DD 1.1-1** - Support continued funding for a common European radio astronomy frequency manager. OSO leadership engages nationally and internationally on interference issues.

Module 2- Onsala Telescopes

DG-2.1 - Operate OSO telescopes within international networks and maintain single dish mode for calibration and astronomical use.

-- **DD-2.1-1** - Fulfil operational goal of delivering (excepting weather issues) >90% of scheduled observations.

DG-2.2 - Expand Swedish user base for VLBI and LOFAR, especially in Transient and Swedish space-weather communities respectively.

-- **DD-2.2-1** - Work within VLBI community for joint calls with other telescopes for transient follow-up, via proposing new joint telescope proposing modes to EVN Board/JIV-ERIC council.

-- **DD-2.2-2** - OSO staff attend national/international Space-Weather meetings and maintain regular EISCAT-3D contacts at least once per year. Engage with European radio astronomy and space-weather communities to respond to EU multi-infrastructure funding calls.

Module 3- ALMA Receivers

DG-3.1 - Maintain leadership in receiver technology - OSO to retain its world-leading standing as a supplier of cryogenic receivers for radio astronomy (especially for ALMA, SKA and VLBI) including developing mm detector technology for use for the current ALMA upgrade and future ALMA-2040 project.

-- **DD-3.1-1** - Maintain collaborations with instrumentation partners for adapting Band 7 SIS mixer technology for use for future ALMA Band 9 and Band 4 upgrades.

-- **DD-3.1-2** - Demonstration of additional mixers for ALMA's band 9 and 4 receiver upgrades.

Module 4- ALMA Regional Centre Node

DG-4.1 - Ongoing User Support.

--**DD-4.1-1** - ARC node fulfils all requirements of European ARC network operational plan. By end of funding period demonstrate increased node support activity via number of project supported.

DG-4.2 - Prepare services for upgraded ALMA Exploit the potential of the OSO Science cloud being developed with SKA node

--**DD-4.2-1** - Implement new ALMA WSU pipelines on OSO science cloud.

DG-4.3 - Expand the Swedish ALMA user base

--**DD-4.3-1** - Organize ARC node visits to Swedish astronomy departments in conjunction with joint telescope calls for JWST and ELT instruments.

Module 5 - SKA Regional Centre Node

DG-5.1 - Node Capacity Development -Develop storage/compute/services of the Swedish SRC node following SRCNet development roadmap.

--**DD-5.1-1** For SRCNet v0.3 node deliver SRCNet assigned resources and services for SKA Array Release 2

--**DD-5.1-2** Procure computing and storage resources in preparation for SRCNet v1.0beta release.

--**DD-5.1-3** For SRCNet v1.0beta node deliver SRCNet assigned resources and services for SKA AA* array release.

--**DD-5.1-4** SRC node to provide early operation phase support to users (2029 and 2030) while continuing development toward full SKA.

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Scientific justification of the infrastructure

Scientific questions

See following page for attachment

Onsala Space Observatory (OSO) is Sweden's world-class radio/mm astronomy and geoscience observatory serving the Swedish and international astronomical and geoscience communities¹. OSO's VR-funded mission is to support Swedish astronomers in using radio observations to address many of today's highest priority questions in astrophysics.

To understand the origins of galaxies, stars and planets, and to answer a myriad other astrophysical questions, astronomers desire the widest possible access to the electromagnetic (EM) spectrum. Within the EM spectrum there are two atmospheric windows allowing signals to reach the Earth's surface, i.e. at Optical/Near IR wavelengths and at radio wavelengths. The radio window, including the (sub)-millimetre wavelengths, spans a very broad wavelength range, within which a wide variety of emission mechanisms operate, each carrying unique information. Narrow frequency band spectral line observations from ions, atoms (in particular, from neutral hydrogen) and molecules trace the temperature, density, chemistry, magnetisation, and kinematics of gas; especially in forming stars and planets, in galaxies, and during the late stages of stellar evolution. Broad-band radio continuum emission traces accretion regions of black holes and their relativistic jets, provides an obscuration-independent tracer of star-formation and reveals the formation and growth of cool dust around young and old stars. The polarization of radio continuum emission also informs about magnetic fields.

Given their rich information content, radio wavelength observations contribute to addressing almost all the major scientific questions in modern astronomy. For some astrophysical questions radio observations are especially important. Many, including the topics listed below, are particularly active research areas in Sweden.

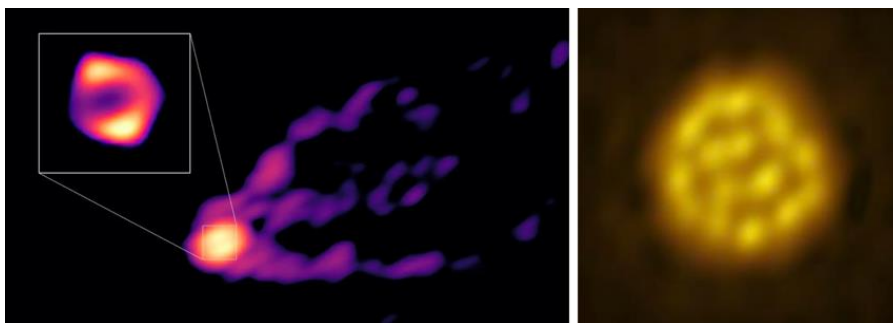


Fig 1. Two recent examples of high-impact OSO supported observations involving Swedish researchers. **Left** - First radio image of a relativistic jet at the centre of galaxy M87 being launched from a black hole (Lu et al 2023, using the Onsala 20m telescope as part of a global telescope array). **Right** - Convection bubbles on the surface of the evolved star R Doradus (Vlemmings et al 2024) made using ALMA.

Q1. Can known physics explain black holes and how they modify their galaxies? High spatial resolution radio observations can probe the structure of black holes on event horizon scales and provide sensitive tests of general relativity while also constraining how black holes produce jets of material (see Lu et al. 2023, Fig 1-Left) expelled at near light speed. Researchers at Chalmers are part of the Event Horizon Telescope (EHT) consortium that has made the first two images of Black Holes. OSO contributes to the EHT by providing critical receivers, software and observing support to enable black hole imaging results.

Q2. How did the first stars and galaxies form? - Observations of neutral atomic hydrogen via its 21 cm wavelength spectral line can be used to study the Epoch of Reionization (EoR) when the first stars ionized the intergalactic medium. A major goal of modern metre wavelength radio astronomy is to understand this period of the universe's history. From metre wavelength radio observations, it is possible to make large scale 3D images of the universe (two dimensions of space and one of look-back time) to directly trace large scale structure and galaxy formation in the early universe. This research area is well established in Sweden, with Stockholm University hosting one of the world's leading groups for the modelling and interpretation of EoR radio data.

¹ OSO's activities within space geodesy and geoscience are funded by the Swedish national land survey organization Lantmäteriet (see *Enabling Research* section). This current proposal to VR specifically concerns OSO's radio astronomy activities but also describes, where appropriate, the strong mutually beneficial synergies between OSO's astronomical and geodetic missions.

Q3. What are dark matter and dark energy and what are their impacts on cosmological models? Radio observations of galactic rotation curves and of cosmic large-scale structures help constrain models of dark matter and dark energy. Large area radio surveys that SKA will conduct will be used to measure, as a function of redshift, the angular scales of primordial Baryonic Acoustic Oscillations imprinted on the distribution of galaxies. This in turn can be used to constrain the properties of Dark Energy, an area of great interest to cosmology researchers at Stockholm and Uppsala universities and elsewhere in Sweden.

Q4. How do galaxies form and evolve over cosmic time? Radio and (sub)-millimetre observations play a vital role in galaxy evolution studies by tracing the mass and kinematics of gas in galaxies and providing estimates of galaxy dust content and give obscuration independent star formation rates. Sweden has recently obtained an ERC Synergy grant (RECAP project, co-PI Kirsten Knudsen) to study the first galaxies formed during the Epoch of Reionization using radio observations in combination with optical observations and numerical simulations. Studying how galaxies evolve over the history of the universe is a major topic of interest at multiple Swedish universities including at Chalmers, Stockholm, Uppsala and Lund universities.

Q5. What are the origins of fast radio bursts (FRBs) and other radio transients? Fast radio bursts (FRBs) are extremely powerful millisecond duration radio bursts of unknown origin that are one of the most mysterious phenomena in current astronomy. Chalmers scientists use the Onsala 25m telescope as part of global radio telescope networks to precisely locate these mysterious bursts to constrain their origin. Similar techniques are used to study the evolving structures of tidal disruption events around black holes, neutron-neutron star collisions and both core-collapse and thermonuclear supernovae. These types of transients are studied by researchers at KTH, Chalmers and Stockholm University who utilize radio data as part of multi-waveband observations and source modelling.

Q6. What is the origin and impact of cosmic magnetism? In interstellar gas magnetic field energy densities can be comparable to thermal energy densities and hence cosmic magnetic fields can have important dynamical effects influencing processes such as star formation. The origin of these large cosmic magnetic fields is not fully understood but likely arises via dynamo amplification of small primordial magnetic fields. Radio polarization observations provide one of the few ways to trace and study cosmic magnetic fields. Researchers interested in using radio observations to trace cosmic magnetic fields are active at Chalmers and at Nordita in Stockholm.

Q7. What are the mechanisms generating coronal mass ejections and space weather? – The Sun is our closest star, studying it allows us to understand stars in general and can also have practical uses for society. Sub-mm wavelength continuum observations of the Sun, possible with ALMA, allow studies of the top of its photosphere, while metre wave observations probe plasma physics in the Sun's extended corona. This latter region produces potentially dangerous coronal mass ejections that can be tracked with radio observations till they interact with the Earth's ionosphere. This is a research area with significant growth possibilities within Sweden, via interaction with the space-weather community, EISCAT 3D etc.

Q8. How do stars and planetary systems form and how do they create the conditions for life? Radio observations can penetrate the dense clouds of dust and gas in star-forming regions, revealing details about protostars and planet-forming disks. Observations of molecular line emission in these objects can reveal chemistry and physical conditions such as density and temperature. Continuum millimetre wavelength observations can probe the regions of disks in which giant planets form, while centimetre wavelength observations can be used to study the dust growth in regions where terrestrial planets like the Earth form. This is a very active research field at Stockholm, Gothenburg, Chalmers and Lund Universities as well as at Nordita.

Q9. What happens as stars age and die? The winds of red giant stars and the explosions of core-collapse supernovae carry heavy elements and microscopic dust particles into interstellar space, where they later become incorporated into rocky planets and even complex living organisms. The mass loss process in evolved stars can be studied in detail using radio observations at millimetre and radio wavelengths, including following the evolving convection cell structure of stars, such as via the recently published ALMA movie of motions on a stellar surface (Vlemmings et al 2024. See Fig 1-Right). Uppsala University and Chalmers host two of the world-leading groups in this field.

Enabling research

See following page for attachment

Onsala Space Observatory provides Swedish astronomer access to radio wavelengths via operating its own telescopes and by supporting Swedish use of international radio telescopes. Onsala's own radio telescopes (Fig. 1 - left) either operate as part of large global radio telescope networks (Very Long Baseline Interferometry (VLBI), see Fig-1middle/right), or as stand-alone single dishes/stations, generating key science results such as the imaging of black holes or the detection of new molecules in space. Innovations derived from the development and operation of OSO telescopes also provide the foundation for the observatory's ongoing success in delivering critical technology to radio astronomy projects world-wide, in turn generating valuable contracts and seeding technical development for Swedish industry (see *Socio-Economic Impacts* section).

In addition to its astronomy role OSO also supports geoscience, primarily via its world-leading role in *geodetic VLBI*¹. These observations define the terrestrial and celestial reference frames and monitor the Earth's orientation and rotation rate, providing vital information for both researchers and for the multi-billion Euro navigation services industry. This activity at OSO is funded by the Swedish national land survey organization (Lantmäteriet) and not VR but is relevant for this proposal because running geodetic and astronomical VLBI at the same site greatly increases the efficiency of both activities.

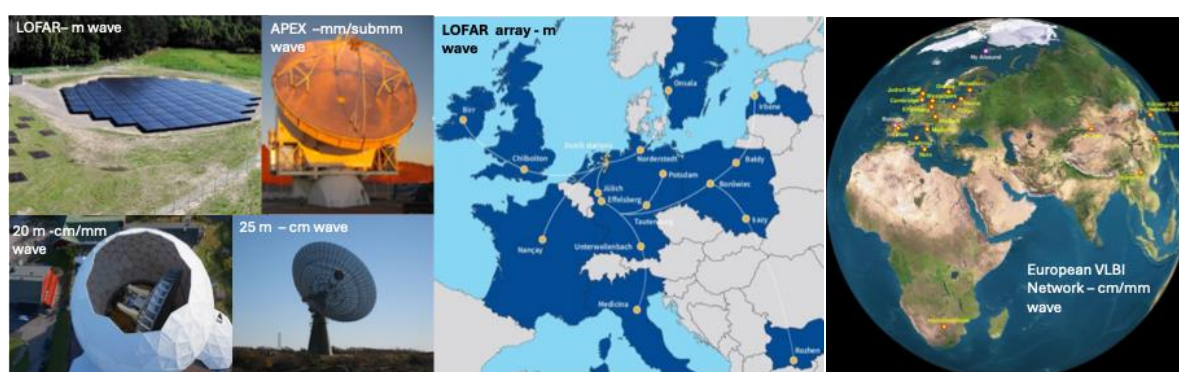


Fig. 1. Left Panel- OSO-operated radio astronomy telescopes and their wavelengths of operation. **Middle and Right panels** – Two example long baseline arrays within which OSO telescopes observe. The middle panel shows the metre wavelength LOFAR array. The right panel shows the European VLBI Array (EVN) managed by the JIV-ERIC, within which the Onsala 25 m and 20 m telescopes operate.

OSO telescopes and VLBI – OSO's radio astronomy telescopes are shown in the left panel of Fig. 1 (see *Module Descriptions* section for more details). The middle and right panels show two examples of the long baseline arrays in which OSO's telescopes participate, which in turn contribute to addressing the following questions in the *Science Questions* section: Q1-Black Holes, Q4-Galaxy Evolution, Q5-Transients, Q6-Magnetism, Q8- Star/planet formation and Q9-Evolved stars. Example OSO high impact science results are listed in "Research enabled during the current grant period" (papers A-D). The impact that VLBI makes to answering the key questions arises because many can only be addressed by observing the fine details of compact objects. At radio wavelengths this requires telescopes with continent or global dimensions, which can be synthesised by combining signals from arrays of dishes or phased-array stations. OSO pioneered the development of the VLBI technique and remains a leader in the field. The VR commissioned 2023 report on 'Quality and impact of physics research in Sweden', available on the VR website, noted in relation to Q1 and Result B above that 'The image of the black hole shadow and the analysis of this image are seen by a wider science community as breakthrough results in astronomy during the last decade. The consistent participation of the Swedish VLBI group is an important part of this success story'.

Prospects for VLBI development are exciting. Sensitivity will increase via new multi-band receivers, with wider bandwidth than for SKA (see below), currently being developed by OSO and others. This follows VLBI's historical role as a technology incubator developing next generation instrumentation. Just as ALMA has already done for mm-wave VLBI (see Fig 1 in *Science Questions*), adding SKA to cm VLBI arrays will further boost sensitivity. Therefore, with the advent of the SKA, the scientific value

¹ Geodetic VLBI observes distant point-like radio sources generated from accreting supermassive black holes and therefore represents a unique and under-appreciated practical use of black holes for societal benefit.

of OSO's telescopes for VLBI will greatly increase, especially since OSO will provide the longest North-South baseline to SKA-mid, maximizing VLBI array spatial resolution in that direction.

ALMA - At the shortest (mm/submm) radio wavelengths the world's largest general-purpose telescope is ALMA, located at high altitude (5000 m) in Chile's Atacama Desert (see Fig. 2 - rightmost panel). Observing time on ALMA is amongst the most sought after of any astronomical telescope in the world. ALMA addresses Science questions Q1-Black holes, Q3-Dark matter, Q4-Galaxy Evolution, Q7-The Sun, Q8-Star/planet formation, and Q9-Evolved Stars. Consistent with its broad scope ALMA contributes to six of our ten listed key publications (papers B and F-I). In addition, our analysis shows that at least 25% of the Swedish astronomical community has used ALMA. OSO has played a major role in the construction of ALMA, including providing the array layout design, developing/building the Band 5 receivers deployed on its 66 antennas; and most recently playing a key role in delivering ALMA's new Band 2 receivers. ALMA's Wide Band Sensitivity (WSU) upgrade, started in 2024, and set to be completed by the early 2030s, will dramatically increase ALMA's sensitivity and data rate. As a critical contribution to the ALMA WSU the OSO infrastructure plans to deliver new ultra-wide bandwidth Band 7 receivers, in return for which Swedish astronomers would receive valuable ALMA Guaranteed Time Observing (GTO). Swedish astronomers are currently amongst the most productive users of ALMA, with this national success in large part due to OSO's ALMA support node which provides Swedish ALMA users with data processing and face-to-face user support. Detailed ARC development plans for the coming grant period (see *Module Description* section) include strong involvement of ARC node staff in WSU commissioning and pipeline development enabling Swedish astronomers to get immediate science return from highly sought-after ALMA WSU data as soon as it is available.

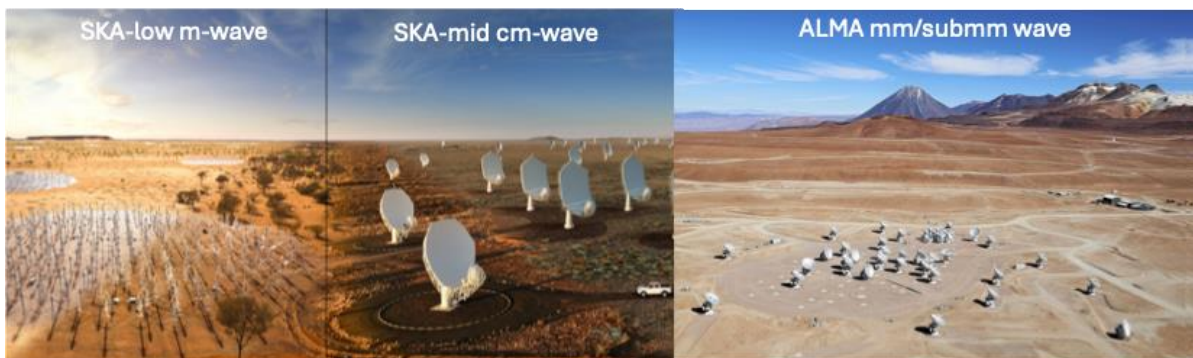


Fig. 2. The SKA and ALMA radio telescopes. The rightmost panel shows an aerial photograph of the ALMA telescope located in Chile's Atacama Desert. The two left-most panels show computer generated images of the Square Kilometre Array (SKA) which consists of a metre wave array (SKA-low, far left) and a cm wave array (SKA-mid, middle panel) – right now under construction in Australia and South Africa respectively.

SKA - OSO has been deeply involved in the design and construction of the Square Kilometre Array (SKA). The SKA telescopes at m/cm wavelengths will, like ALMA at mm/sub-mm wavelengths, be one of the cornerstones of 21st century astronomy. The SKA will consist of (see Fig. 2 - left) a metre wavelength array in Australia and a centimetre wavelength array in South Africa. OSO has designed key hardware components of SKA which are now being produced by Swedish industry (see *Socio-Economic Impact* section). OSO is also rapidly building up its Swedish SKA Regional Centre (SRC) node to archive and process the data products produced from both SKA telescopes as they start to become available from 2027 onwards. SKA addresses *all nine* of the identified key science questions and is specifically designed to provide transformational results towards Q2-EoR, Q6-Magnetism and Q5-Fast Radio Bursts and other transients. A review of the membership of SKA Science Working Groups (SWG) shows that at least 20% of Swedish astronomers are members of one or more groups that are actively planning to use the SKA. While SKA is still under construction Swedish astronomers are already active in publishing science results from SKA's precursor and pathfinder telescopes, for instance from LOFAR, as illustrated by publications A and J in the Key Publications list. As well as serving Swedish researchers already active at cm/m wavelengths, it is expected as evidenced by SWG membership, that new communities in Sweden will become users of SKA and its data products, from cosmologists studying dark matter/energy, to those studying space-weather in our solar system.

Communication with the research community

OSO spends significant effort maintaining and developing communication with its current and potential user community - both to communicate opportunities, such as upcoming observing proposal deadlines, meetings etc. and to canvas community input for determining OSO's future priorities. Specific OSO actions include:

- Identifying and keeping contact with users is a vital first step in the above consultation process. Existing users, with their permission, are systematically added to OSO's email contact list, while potential future users can also sign up this list to receive regular news including OSO's biannual astronomy newsletter. In addition, we maintain Swedish-focused mailing lists for both ALMA and SKA news.
- OSO also occasionally uses the general communication channel organized by the Swedish National Committee for Astronomy to reach astronomers in all of the major Swedish university astronomy departments, in order to advertise annual national meetings on radio astronomy topics including Swedish SKA Science days and ALMA status meetings. At these meetings there are always discussion sessions on user needs.
- There is always strong OSO presence at the national astronomy meeting ('Astronomdagarna') at which OSO staff generally present the status and science potential of radio astronomy projects.
- OSO polls its community with questionnaires on specific topics, most recently on the question of future computer processing needs for analysing radio astronomy data.
- Inputs on future strategic directions for OSO are obtained via OSO engagement with the various discussion forums that exist within Swedish astronomy, including via participating in discussions about the future development of Swedish astronomy at the National Committee for Astronomy, discussions at the national astronomy meetings etc. These inputs are then further discussed within the OSO Steering Committee, which itself has broad representation across Swedish academia, before OSO's future goals and strategy are set.

The Swedish research community's contribution to the field

Astronomy use of the infrastructure - Several Swedish research groups that are users of the OSO infrastructure operate at the frontier of their respective astronomy research fields. A number of these groups also support the OSO activities by providing scientific expertise and use cases for e.g. SKA/ALMA data challenges, development of advanced data analysis tools, machine learning data analysis methods and specialist observing modes. Examples of such interactions include those with the group of Prof *Garrelt Mellema* working in Epoch of Reionization (*EoR*) studies at Stockholm University, and the groups of Profs *Kirsten Knudsen* and *Susanne Aalto*, working in the galaxy evolution area at Chalmers.

Instrumentation Development - At Chalmers, Prof *Vincent Desmaris*, head of OSO's Group for Advanced Receiver Development (GARD), is a world leading researcher in radio astronomy receivers. Under the leadership of Prof Desmaris and its previous head Prof *Victor Belitsky* GARD has delivered Band 5 and 2 receivers to ALMA. receivers for APEX and also provided key staff to deliver Band 1 on the SKA-mid telescope. Prof Desmaris uses academic funding to develop new detectors based on his expert knowledge of applied quantum mechanics. GARD group infrastructure effort then develops this technology through medium and high Technological Readiness Levels (TRL) all the way through to the full production of receivers for telescope deployment.

National interest

Fulfilling the needs of the research community

The area description in the VR infrastructure proposal call accurately describes OSO's broad role as both a national radio observatory operating its own telescopes and as the Swedish node within international radio telescope projects; all related to OSO's goal of providing Swedish astronomers the fullest possible access to radio wavelengths.

OSO's own telescopes are mostly used within Very Long Baseline Interferometry (VLBI) arrays, producing unique science results in areas such as black hole imaging and fast radio burst location. The area text also describes OSO's role in supporting Swedish users in using international radio astronomy facilities, such as ALMA (Atacama Large Millimeter/submillimeter Array), JIVE (Joint Institute for VLBI) the central operating organization of the EVN (European VLBI Network), LOFAR (Low Frequency Array), and the SKA (Square Kilometre Array).

Towards the above international projects Onsala provides user support, works with technology development and provides computational resources. OSO also, as noted by the area text, works closely with Swedish companies in advanced technology development for digital receivers for both the SKA and for the ongoing ALMA upgrade.

Uniquely amongst all radio observatories worldwide OSO has developed and built receivers for both the submm/mm wavelength ALMA array and for the cm/m wavelength SKA array. OSO is now positioned to supply the next generation of receivers to both telescopes to continue OSO's extremely successful record of resource return to Sweden from international radio astronomy projects, both to academia and to Swedish industry.

By directly funding, as outlined in this proposal, the final development and construction of new ALMA Band 7 receivers, Sweden will obtain in return access to extremely valuable guaranteed ALMA observing time for its astronomers.

A key OSO goal is developing high-capacity data storage and computing infrastructure to deal with the avalanche of data from SKA and the upgraded ALMA. In the future, access to computational resources, and to advanced ML/AI software for radio astronomy analysis, are expected to be critical factors influencing the international ranking of Swedish astronomy. To this end OSO is building up a large science cloud facility. Currently this is being developed with Chalmers e-commons as part of international efforts which are still experimental, for full operations provision in the 2030's using cost effective NAISS resources is envisioned.

Expected user groups

OSO's users generally obtain their radio telescope time by applying to one of the telescope networks in which OSO's telescopes participate, or to the international radio telescopes for which OSO provides data user support. A small fraction of users instead apply directly to OSO to use its telescopes in single-dish/single-station mode. Currently OSO users are almost exclusively academics. Proposal team membership spans a wide career level range from PhD students through to full and emeritus professors.

Over the period of this proposal, we expect, as SKA comes online, to see many more Swedish scientists that use centimetre and metre wave observations. Also, we expect an increased geographical spread in the host university of OSO's Swedish users, as evidenced by attendance at the two national SKA meetings held to date (Stockholm in 2023 with 61 attendees and Gothenburg in 2024 with 65 attendees).

Because at cm/m wavelengths a larger field of view can be observed at once, projects at these wavelengths often involve surveys of large sky areas. Such projects often have the status of 'Key Science Projects' and can involve hundreds of researchers from all over the world. We expect that in the future OSO will be involved in supporting a higher fraction of such survey observations and large teams rather than single source observations led by small groups.

A significant increase in the user base for VLBI is expected as the SKA-mid array is added to VLBI arrays, greatly increasing their sensitivity. A particular growth area is expected in transient source observations and in multi-messenger astronomy. Transients will be detected in great numbers by SKA and then will be followed up by VLBI to provide accurate positions and to track their structural evolution.

We also expect a large increase in the number of ALMA users due to the Wideband Sensitivity Upgrade increasing ALMA observing speed, more shared observation calls with e.g. the JWST and ESO telescopes, and Swedish access to Guaranteed Time Observing from Swedish Band 7 receiver delivery. We expect via the above measures that ALMA will be used by an ever wider set of Swedish research groups.

An expansion in users beyond academic astronomers potentially involves companies or research groups working with ML/AI who may be interested in accessing large data volumes (0.5 - 1.0 Exabyte/yr from SKA) for training or for space agencies/companies using radio telescopes for data downlink from space.

Available infrastructures and methods

Answering Swedish scientists' key astronomical questions requires collecting high-quality observations of the universe. Although increasingly supplemented by other cosmic messengers, such as neutrinos, cosmic rays and gravitational waves, most information still comes to us via electromagnetic (EM) radiation. In order to answer their scientific questions, Swedish astronomers benefit from having access to as many wavelengths of the EM spectrum as possible.

OSO's specific role is providing access to the radio part of the spectrum (from meter to millimeter wavelengths). There are no other local or national infrastructures that provide this. Considering international infrastructures, OSO's complements the access Swedish scientists have to non-radio wavelengths via Sweden's membership in ESO for large collecting area ground-based optical/IR telescopes and its membership in ESA for access to space telescopes at wavelengths including X-ray and gamma-ray, which can only be observed from space.

OSO provides radio access to Swedish scientists in part via its own telescopes operating as elements of international telescope networks (or in standalone mode) and in part via promoting Swedish involvement/use of the large flagship radio telescopes ALMA (submm/mm wavelength) and the coming SKA (cm/m wavelengths). OSO is part of the group of national radio observatories that have together designed and built ALMA and SKA. OSO plans to continue to contribute key technology to upgrading both telescopes, in return bringing back both valuable observing time to Swedish astronomers and contracts to Swedish industry.

While ESO operates the European activities of ALMA, it coordinates support for ALMA users through an international network of ALMA Regional Centre (ARC) nodes, including the ARC node at OSO. Hence, OSO's other role toward international telescopes is supporting Swedish users via expert user and computing help. OSO's support scientists guide users through all the steps of proposing, scheduling and reducing data. Data reduction also requires access to significant computing resources; providing this capacity for Swedish users, including hosting and developing the necessary software collectively developed by the international radio astronomy community, forms a major part of OSO's future development plan. The Swedish computing node plans within global compute support networks for ALMA and SKA plans to specialize in areas of particular interest to Swedish astronomers.

Accessibility for users

Applications to use OSO's telescopes or to use its user/computer support functions are mostly handled via mechanisms within those international radio astronomy projects, such as the EVN/JIV-ERIC and LOFAR-ERIC, in which OSO is a partner.

For ALMA, Swedish astronomers compete for the 34% of European time. Successful Swedish proposals are assigned to the Onsala ALMA Regional Centre node to give user support. Given the high oversubscription ratio (typically 8.4 for European ALMA time), access is limited. If Sweden gets guaranteed observing time in return for Band 7 delivery, then proposals made for use of this time would greatly increase Swedish access.

SKA precursor telescopes like MeerKAT in South Africa have open observing calls for which Swedish astronomers are successful in obtaining time. An important part of the proposal application process is to show that the proposing team has access to sufficient computer resources to handle the data. For this purpose resources of OSO's Swedish SKA Regional Centre node are made available to be included in Swedish proposal applications.

The exact mechanisms that SKA will use for its proposal handling have yet to be defined but are likely to be similar to ALMA except that a larger fraction of time will be awarded to large programmes

In addition to the above a small fraction of OSO's total users during the coming grant period are expected, as now, to apply directly to OSO for single dish/single station use of OSO's telescopes (i.e. stand-alone observations using Onsala's LOFAR Station, 25 m or 20 m telescope).

To decide which proposals are observed telescope Time Allocation Committees (TACs) assess incoming proposals based entirely on the criteria of project's feasibility and scientific merit. Increasingly anonymous review is used in which TAC members do not know the identity of the proposers; this policy after being applied on ALMA has been shown to increase gender equity and the fraction of time going to younger researchers.

Currently radio telescope time, although in principle freely open for any person or company to apply for, in practice is exclusively used by academic researchers. As is the norm in astronomy generally no user fees are charged to successful proposers. Potentially in the future companies may be interested in accessing large radio astronomy data bases (i.e. 0.5 - 1 Exabyte/yr from SKA) for training ML/AI. For this use case and for use for data download from space missions fees would be charged.

Added value of national infrastructure

Radio astronomy is a global 'big science' in which Sweden's involvement requires a national foundation, just as is the case in most other countries. OSO's main role as a national infrastructure is to provide Sweden's national link to international radio astronomy activities. OSO co-observes with its telescopes as part of international VLBI and provides access to Swedish users to large projects such as ALMA and SKA. OSO also realizes Sweden's national strategic goals for generating industrial return from big science infrastructures as a driver for innovation within Swedish industry. OSO has a vital space geodesy role in delivering Earth orientation services for society, and is also active in public Outreach and Education.

OSO is part of a global network of national radio observatories that forms a global ecosystem for radio astronomy development. *It is important to realize that the global flagship radio astronomy projects ALMA and SKA have not been designed and built by their coordinating/operating organisations ESO and SKAO respectively, there are for instance no labs for developing ALMA and SKA receivers at either organization. These two flagship observatories have been designed and built at the system and component level largely by the national radio astronomy observatories, such as OSO,* working together with their industrial partners.

OSO has played a major role in building both ALMA and SKA while also operating a leading VLBI station for astronomy and geodesy, contributing multiple local telescopes, with a global impact significantly beyond what would be expected by a country the size of Sweden. Over the last 10 years OSO has accomplished all of the following; running operations and development on multiple local radio telescopes, delivering front-line receiver instrumentation to the two largest international telescope projects (ALMA and SKA), in the process generating return in contracts to Swedish industry larger than Sweden's total investment in the latter project. Last but not least it has provided key user and data processing support for VLBI, ALMA and for SKA precursor telescopes supporting world-class science.

The above multiple achievements have been possible only by the great dedication of OSO's staff, via exploiting synergies with other infrastructures in Sweden such as e.g. MyFab for nanofabrication clean room facilities, and via OSO's close connections to local industry, in part established through the many people OSO has trained over the years

Implementation, leadership and organisation

Description of modules

See following page for attachment

Module descriptions are given below followed by a justification of module choice. While all modules involve international activities (see *Enabling Research* section), it is assessed that only Modules 3 and 5 fit VR's definition of having infrastructure international project subsidiary focus. Costs referred to are listed in the budget spreadsheet, while the SG, DG codes link to *Science/Development Goals*.

Module 1- Leadership and central functions – This module contains salary costs for OSO's *Director, Deputy Director* and *Scientific Secretary*. Costs also include the astronomy share (i.e. non-Geoscience part) of non-office rents for labs, technical buildings, infrastructure IT costs, OSO leadership travel costs and the costs of the OSO Steering Committee. A fee covering OSO's share of the salary costs of a frequency manager employed by the European radio astronomy community, working within the international radio frequency allocation process, is also included within this module's budget.

Module 2 – Onsala Telescopes – OSO operates, at its Swedish west coast site (see *Enabling Research* Fig 1 for telescope images), OSO's metre-wavelength **LOFAR** phased-array station, its centimetre wavelength **25 m** diameter dish and radome-enclosed mm wavelength **20 m** telescope, (50% shared between geodesy and astronomy). The site also hosts the Onsala Twin Telescope **OTT** used only for geodetic observations and hence outside the scope of this funding proposal. Finally, OSO retains a limited involvement in the mm/sub-mm **APEX** dish in Chile (see details below). The above telescopes operate almost entirely within Very Long Baseline Interferometry (VLBI, see *Enabling Research*) arrays, although each Onsala telescope also has a standalone single dish/single station mode used for calibration, which is accessible for science observations via user proposals made to OSO. The VLBI arrays in which OSO's astronomy telescopes participate are run by two ERICs with Swedish membership; namely the Joint Institute for VLBI ERIC (JIVE), which coordinates and processes data from the European VLBI Network (EVN) at cm wavelength, and the LOFAR-ERIC operating the LOFAR International Telescope at metre wavelengths. The current five-year funding cycles for these two ERICs extend to the end of 2029 and 2028 respectively. Sweden has commitments to both ERICs to operate its telescopes at Onsala as part of their network operations.

Concerning APEX, as part of OSO's strategic re-prioritization to allow for SKA operations costs (see *Budget Justification* section), OSO will as planned, withdraw from APEX's main single dish observing programme by the end of 2026. OSO intends however, to maintain its receivers installed at APEX which are essential for VLBI black hole imaging observations, which OSO will continue to support. This residual OSO engagement requires 1.1 FTE of research engineer effort to support VLBI observations in Chile. This small total residual APEX effort has high impact since it secures Swedish involvement in the productive Event Horizon Telescope black hole imaging project while providing access to a dish on which to demonstrate new ALMA receivers (see Module 3 below).

Due to retirements, and reduced Module 2 workload from leaving APEX single dish observing, module personnel from 2027 to 2028 will be reduced by 1.7 FTE. This leaves three telescope astronomers (1.8 FTE) to operate the 20m, 25m and LOFAR telescopes plus a total of 7.7 FTE of research engineer effort to operate, maintain and upgrade these telescopes. This comprises 60% of the total effort of the OSO Technical Support Group (TSG) unit (the remainder of the TSG effort supports OSO's geoscience mission) plus 1 FTE effort from the GARD group. The total personnel in this module has reduced in recent years and the proposed personnel level is the minimum needed to fulfil OSO commitments to LOFAR-ERIC and JIV-ERIC (DG-2.1) while also working to extend the VLBI user base (DG-2.2). The budget module contains costs for service costs (compressor, radome, uninterruptable power supply, vehicles). These costs are based on historical mean costs as are costs for replacing failing equipment, renewal of lab equipment, and purchasing recording media for VLBI. All these items have 10-yr lifetimes. Also included in this module's budget is the astronomy share of data link costs, the electricity costs of OSO astronomy telescopes, costs of telescope control computers and network, travel to APEX for VLBI observations and receiver service, general travel and the rental costs on the field on which the OSO LOFAR station is located.

Membership of VLBI networks requires the continuous upgrade of OSO's telescopes to remain compatible with array standards (SG-2.1). The cm/mm VLBI network development plan for the current period requires that OSO's 20 m telescope is upgraded with a Tri-band receiver that can *simultaneously* observe at 1.3 cm, 7 mm and 3 mm wavelengths, plus a wideband CX-band receiver covering 2 cm to 7 cm wavelength. The Triband receiver uses its long wavelength data to remove

atmospheric effects at short wavelengths, dramatically increasing the number of sources in which black holes and jet formation regions can be imaged (see Fig 1, *Scientific Questions*). This module's budget includes the component costs of the Triband and CX receivers (each with 20 yr lifetime). OSO's designs for the two receivers incorporate innovations which will enable them to be the world's most sensitive at their respective wavelengths. Successful delivery of both receivers will position OSO and Swedish companies to supply SKA's next generation Band 5 and 6 receivers in the early 2030's, given the overlap in wavelength with OSO's new receivers. OSO is seeking external sources of funding for a new dish to replace the 25 m dish to improve sensitivity and to optimize co-observing with the SKA (see *Long-term plans* section). If this effort is successful, the above receiver funds could, with VR permission, potentially be used to cover costs of receivers for this new dish.

Module 3 – ALMA Receivers – ALMA is the world's premier telescope for millimetre and submillimetre astronomy (see *Enabling Research* section) - and indeed one of the world's most sought-out telescopes at any waveband. The very high Swedish astronomy community interest and exploitation of ALMA is described in the *Current Operations* section with 25% of all Swedish astronomers being ALMA users, while 12.5% of the 4228 referred ALMA papers published since ALMA's inauguration in 2013 till today having one or more Swedish authors.

Sweden via OSO has also played a key role in building ALMA, not least via the receivers developed by OSO's Group for Advanced Receiver Development (GARD). GARD designed and delivered the first six ALMA Band 5 receivers and then shared the full production run of 70 ALMA receivers with the Netherlands NOVA organization. Following this from 2019-2023 GARD designed and built the first six ALMA Band 2 cartridges. The new ALMA Wideband Sensitivity Upgrade (WSU) project will dramatically increase the sensitivity and observing speed of ALMA via a four-fold increase in receiver bandwidth. The first Europe assigned receiver band to be upgraded to WSU standard is Band 7. In recent years GARD, financed by OSO's VR infrastructure funding and augmented by ESO ALMA upgrade study financing, has developed a unique new technology platform that enables wideband superconducting mixers for Band 7. These new mixers have impressive performance, meeting the four-fold bandwidth expansion goal while also having lower noise than current narrower band mixers, approaching the theoretical quantum limit. All other components of a complete WSU Band 7 receiver have also been developed by GARD. These components will be incorporated into a prototype WSU Band 7 receiver planned to be demonstrated on-sky on the APEX telescope latest early-2027.

Whereas the original suite of ALMA receivers was financed directly by ESO ALMA construction funding, for WSU receiver upgrades ESO has adopted a funding model closer to that used for its optical-IR instrumentation. In return for national funding for receiver construction ALMA Guaranteed Time Observing (GTO) will be generated. This new policy will allow Sweden to obtain extremely valuable science return to its astronomers in return for GARD's world-leading technology (SG-3.1). Full national funding of GARD personnel costs for Band 7 delivery (see below) will generate for Swedish astronomers 145 hrs of ALMA Guaranteed Time Observing (GTO). This is even more than the average of 130 hrs of ALMA time per annual observing cycle obtained by Swedish astronomers via proposals to the annual open calls. This open time is obtained in the face of huge competition, and given the extremely high ALMA oversubscription ratio of 8.4 it comes in piecemeal chunks. In contrast, a large block of guaranteed time can be used to make major advances in one or two science areas of broad interest to Swedish astronomers. Band 7 is one of ALMA's most used, covering a critical carbon monoxide line, and 25% of the time may be used for other bands. OSO as a national infrastructure is committed to maximizing and diversifying ALMA use and the OSO ARC node (see Module 4) is well positioned to coordinate with the Swedish community the contents of the umbrella science exploitation plan that will accompany the Swedish led bid to construct Band 7 (see below). Two possible science themes of broad interest at multiple Swedish universities (see *Science Questions*) are high-redshift galaxy formation and evolution, and evolved stars in our galaxy.

ESO, as the European partner in ALMA will, likely in early 2026, run a process to select a consortium to supply Band 7 with the selection criteria being both technical performance and how much national funding each consortium can bring. Although GARD in collaboration with its long-term partner NOVA in the Netherlands is ahead technically, we know there is a rival consortium competing (see *Risks* section). Module 3 requests VR international project funding for final development and delivery of GARD technology to supply Band 7 (SG-3.1, SG-3.2) and to develop its technology for other ALMA upgrades (DD-3.1) both within WSU and toward its successor upgrade project ALMA 2040. This

work will occupy all of the GARD group's effort during the next funding period. The delivery of the Band 7 project by GARD will be regulated by a contract with ESO who will oversee the project (see *Leadership* section). Following the VR infrastructure call instructions, we assess that Module 3 fulfils all the requirements needed for having international project subsidiary focus which is fully funded by VR. Chalmers will however still make significant contribution via the equipment and services, provided by the Myfab clean room infrastructure. In addition, non-infrastructure Chalmers academic funding pays on average at GARD for two PhD students and provides the base academic funding for two faculty members. The budget for Module 3 requests funding for 6.3 FTE, based on previous GARD experience of Band 5 full production. Clean room user fees, workshop costs, travel, IT services and lab rents, as itemized in the excel budget spreadsheet sum to 1.2 Mkr/yr, with the cost of buying components for ALMA receiver development other than Band 7 estimated as 0.4 Mkr/yr.

Module 4 – ALMA Regional Centre (ARC) node - The European ARC network, coordinated from the ESO central ARC node in Germany, supports ALMA users across Europe. It forms the interface between the ALMA observatory and the user community throughout a project's lifecycle. The network's goal is to maximize ALMA's scientific return for European users with each ARC node being funded by national sources. The Nordic ARC based at OSO supports (DG-4.1) Swedish and other Nordic users (80% of its users are from Sweden). The ARC nodes provide core functions such as face-to-face support, help with data reduction, and community development. The nodes also develop specialized data reduction software, assist with archival research, and prepares the user community through tutorials and open days. The Nordic ALMA Regional Centre (ARC), operational for over a decade, remains crucial to maximizing Swedish ALMA exploitation and has been critical in supporting the 25% of all Swedish astronomers that have used ALMA. The publications supported by the ARC node are amongst the most numerous and impactful of all OSO publications (e.g. key publications B, E, F, G, H, I).

As described earlier the ALMA Wideband Sensitivity Upgrade (WSU) project will implement a major enhancement to ALMA capabilities. By the end of this decade, a new suite of receivers (see Module 3) will increase ALMA bandwidth by a factor of four while a new correlator will revolutionize spectral line exploration, allowing higher bandwidth and spectral resolution. The increased data rate and volume necessitates new techniques and a new data reduction software package, RADPS. The Nordic ARC will assist Swedish users in managing these new techniques and software (SG-4.1, DG-4.2). Synergies with new instruments like the JWST, the SKA and ESO's ELT will expand the ALMA user community, (DG-4.3) bringing in new users who can benefit from expert support from the Nordic ARC. The ever-rising oversubscription of ALMA (up to 8.4 for European users in the last proposal round) has also increased interest and usage of the ALMA Science Archive. The Nordic node of the European ARC already is a leader in implementing Machine Learning techniques to mine the ALMA archive and will develop this expertise further in coming years, lowering the threshold for archive-based research and broadening the Swedish ALMA user base.

The Nordic ARC node plans in the coming period several distinct activities, including community outreach, contact scientist support of approved ALMA observations, data quality assessment, face-to-face data reduction and software development. To meet the current needs of ALMA users as well as the increasing needs in preparing for the ALMA WSU upgrade (SG-4.1), including the switch to a new data reduction package, an additional support scientist is proposed specializing in software and pipeline development, bringing the ARC Node total FTE to 3.2. The data volumes from ALMA after the WSU are anticipated to be ten times the current rates. To manage the ALMA WSU data, the same computer system used by the Swedish SKA Regional Centre node (see Module 5) will also accommodate the increased ALMA compute and storage requirements (see also the *Data Handling and e-infrastructure* section) with this module paying 10% of the cost of these new computer resources, i.e. 1.4 Mkr capital costs in 2027 and annual running costs of 0.1 Mkryr.

Module 5 – SKA Regional Centre (SRC) node - The SKAO telescopes, when in full operation, will generate 0.5 – 1.0 Exabytes/yr of data that must be permanently archived and further processed to achieve SKA's science goals. A critical SKA design choice, that differs from ALMA, is that its permanently user accessible archive will be distributed around the SKA member countries. Each node of the SKA Regional Centre Network (SRCNet), financed by national sources, is expected to provide storage and computation in proportion to that country's share of the SKA, i.e. 1.5% for

Sweden. Despite being physically distributed the collection of nodes forming SRCNet will be highly interoperable with users performing workflows on their SKA data without knowing where their data resides. The size and ambition of SRCNet makes it a major international project alongside SKA telescope construction/operation, to which SKA member countries are committed as an essential part of delivering SKA. The requirements for a Swedish SRC node were fully described in the 2019 proposal submitted to VR requesting funding for Swedish participation in SKA.

Organizationally SRCNet is led by a management team based at SKAO headquarters. Personnel, compute and storage is pledged every 6 months by each country to the project via a Resource board. It will be VR's responsibility to appoint/confirm Sweden's board member, currently OSO's Deputy Director, once Sweden becomes a full SKA member in mid-2025. Personnel effort to SRCNet pledged for its streams of development, network prototype operations and science pipeline development, is organized by an agile-scrum system. services, compute and storage delivered by each country are carefully tracked. It is planned in future to use the accumulated national SRCNet accredited contributions for assigning SKA/SRCNet access to different countries. Given its tight international project organization and the goal of designing and building up SRCNet through its development phase, this module fulfils all the requirements for having *international project subsidiary focus*. Chalmers will still however significantly contribute to the SRC node effort given that at present it is being developed in very close synergy with the Chalmers e-commons organization. Chalmers e-commons is a unit of currently 17.5 FTE that concentrates all the university's HPC, ICT, IT and AI/ML knowledge into one place. The expertise provided by e-commons has huge value in allowing Sweden to deliver its first prototype SRC node efficiently.

Given that nothing quite like SRCNet has ever been built it will be in its development phase till the end of the decade. During this phase it will be a great advantage to run local hardware hosted by Chalmers e-commons and its C3SE HPC centre. The Swedish SRC node via Chalmers e-commons has made informal contacts with NAISS, the Swedish national organization for supercomputing, hosting a successful visit of NAISS experts in August 2024. Once after 2030 SRCNet moves into a fully mature operational phase, with technical specifications settled, then for reasons of economic efficiency NAISS resources will almost certainly be optimum for providing Sweden's SRCNet contribution. Detailed discussions with NAISS will start mid-2027 about including in OSO's 2029 VR application a request to use NAISS compute and storage services from 2031 onward.

Currently a base level of compute and storage (lifespan 6 years) is being deployed during 2025 which will satisfy SKA and ALMA needs through 2027. During 2027 an additional investment will be needed, as outlined in the *data handling* section, if the Swedish node is to fulfil the plan in the current SRCNet roadmap. Module 5 will pay 90% of the purchase cost of this new compute and storage shared with Module 4 (i.e. 12.2 Mkr cost in 2027 to Module 5) and will pay the same fraction of operations costs (i.e. 0.9 Mkr/yr). In addition, the budget requests 250 kkr/yr to buy e-commons expertise in ML/AI to continue the node's successful development of source finding software for SKA (see *e-science user tools* section). Since 2023 three staff have been recruited for the SRC node, balancing retirements in other parts of OSO's organization. These recruitments combined with reassigned OSO staff give a current node staffing level of 2.9 FTE. The SRCNet development roadmap defines the node personnel requirements needed for 2028 -2030 as a base amount plus a component proportional to the size of a node's compute and storage, proportional to a country's SKA share. This gives a Swedish node requirement of 4.0– 4.5 FTE. The budget for this module includes funding for two SRC node hires, each with 0.7 FTE infrastructure contribution, which in combination with existing staff will achieve the above target. This staff level will be sufficient for implementing node services and developing the Swedish SKA user community (DG-5.1, SG-5.1).

Choice of Modules and interconnections – This proposal takes the opportunity to reduce the number and rationalize the content of OSO's activity modules. Module 2- OSO *telescopes* - combines current modules for OSO's separate telescopes. Given that there are common shared costs between OSO's telescopes this choice simplifies the structure. *Module 3 – ALMA Receivers* replaces today's general module on mm receiver development. *Module 4 – ALMA Regional centre node* and *Module 5 - SKA Regional centre node* replace today's single Observational support module. This split is motivated by the different organizational characters and development state of the ALMA and SKA nodes, with the latter being part of a highly centralized international development project.

Description of infrastructure's leadership

See following page for attachment

OSO strategic, scientific, and operational leadership – OSO’s strategy is set by its Steering Committee (OSC). The OSC also approves the infrastructure’s annual budget and advises the OSO management on OSO operations. The Chalmers university president appoints the OSC members in consultation with VR. The current committee’s chair is Jan-Eric Sundgren, who has extensive experience of management and policy issues relating to science infrastructures. Of the six other committee members four are faculty astronomers, respectively employed at Stockholm, Uppsala, and Chalmers universities and at ASTRON, the Netherlands national radio observatory. Two OSC members are space geodesy experts and managers from the German and Norwegian land survey agencies. The current OSO strategy, with minor modifications, is based on the OSO 2020-2030 Strategy document set by the OSC in 2019. The OSC holds at least two face-to-face meetings per year during which the OSO strategy and its implementation is continuously reviewed. The OSO infrastructure’s scientific and operational leadership is provided by its Director (Prof John Conway) assisted by its Deputy Director (Prof Wouter Vlemmings).

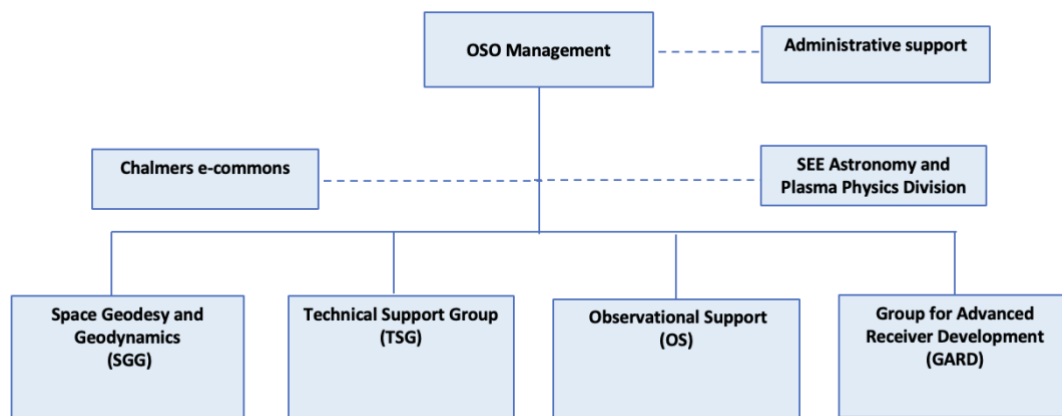


Fig 1 - Organogram showing the OSO internal line organisation (see text).

OSO organization – The OSO infrastructure is hosted at Chalmers by the OSO Division, one of five Divisions within Chalmers’s Department of Space Earth and Environment (SEE). The OSO infrastructure is the dominant activity of the OSO Division and provides nearly all its budget. Internally OSO has a small management group which leads four operational units (see Fig 1, bottom row), with each unit employing approximately 10 people. In addition, small amounts of specialist personnel effort (1 to 2 FTE) are bought-in from other parts of Chalmers, i.e. developers from the Chalmers e-commons organization and a scientific secretary from the SEE Astronomy and Plasma Division). OSO’s host SEE department funds 2 FTE of OSO administrative support, for a general administrator and a finance officer. The latter carefully tracks spending and works closely with the OSO leadership to ensure economic effectiveness. Within the OSO Division there are three base-financed academic faculty working in space geodesy and two faculty working in quantum electronics research relevant for radio astronomy instrumentation work within the GARD unit. The OSO division’s infrastructure and academic budgets are kept rigorously separate, with each having its own cost centre

OSO’s four operational units collect common personnel skills and competences. There is a matrix relationship between these units and OSO’s telescope-based modules (see Fig 2). In summary the Space Geodesy and Geodynamics (SGG) unit supports the OSO infrastructure’s geoscience operations, which are fully funded by the Swedish national land survey. The Technical Support Group (TSG) maintains and upgrades the radio telescopes and geoscience instruments at Onsala, with its effort split 60% for Radio Astronomy and 40% for Geoscience; only the former part is VR funded. The Observational Support (OS) unit contains PhD qualified support astronomers who maintain the scientific operations of the OSO radio telescopes and staff OSO’s ALMA and SKA Regional centre nodes. Unit members have 30% personal astronomy research time funded by Chalmers, outside of its national infrastructure contribution. Offering such research time is the norm at astronomical observatories worldwide; without offering such time it would be impossible to recruit and retain suitably qualified support scientist staff. The main role of the Group for Advanced Receiver Development (GARD) is developing advanced millimetre wavelength receivers, especially for ALMA,

although GARD also supports the TSG unit in developing Onsala telescopes and SKA receivers. Unlike the other units located at Onsala, GARD is located at Chalmers main campus close to the MyFab infrastructure clean room facilities. To plan and coordinate all OSO activities a detailed planning process, linked to OSO's budget definition activities, occurs annually from the end of August to mid-October. OSO's work done in the previous year is then followed up and analysed for lessons learned from January to March as part of the process of forming a comprehensive OSO annual report (see OSO website).

Module	OSO Unit			
	SGG	TSG	OS	GARD
M2- OSO Telescopes				
M3 - ALMA Receivers				
M4 - ALMA Regional Centre user support				
M5 - SKA Regional Centre user support				
Geoscience Infrastructure				

Fig 2 – Matrix relationship between units and modules. Light blue indicates partial involvement.

Below the management of each module is described dividing between those with national subsidiary focus and those with (international) project subsidiary focus.

Management of OSO national activities – Besides **Module 1 (OSO Leadership)** OSO's national infrastructure activities lie within two activity modules. **Module 2 (OSO Telescopes)** operates and develops the OSO astronomy telescopes. As illustrated in Fig 2 this module utilizes the skills of three OSO units (TSG, OS and GARD) whose contributions are coordinated by means of regular multi-unit meetings. **Module 4 (ALMA Regional Centre - ARC)** activities involve staff from a single unit i.e., Observational Support (OS) with module activities ultimately directed by OS line management. To plan its work in detail the ARC node holds weekly internal coordination meetings and also regular meetings with the European ARC network coordinators at ESO and with the other ARC nodes around Europe that serve other European countries and regions.

Management of OSO international project activities. Activity Modules 3 and 5 comprise OSO's international project activities. **Module 3 (ALMA Receivers)** hosts the work to develop and construct next generation ALMA receivers i.e. for Band 7, followed by Band 9 and then possibly other bands. All ALMA receiver development work is carried out in close coordination with ESO which signs detailed contracts with GARD specifying requirements and the timeline for deliveries. ESO holds regular review meetings for each such project. Only by delivering to agreed standards and on schedule does Sweden/GARD receive Guaranteed Time Observing (GTO) or alternatively agreed direct funding from ESO (currently the case for ongoing smaller ALMA development projects). **Module 5 (SKA Regional Centre, SRC)** is the Swedish part of an SKA wide international project to build the SRC Network (SRCNet) to host and process SKA data. As established by the SKAO council, SRCNet is implemented as a development project led by a project manager and core management group located at SKAO headquarters. In a similar way to how the WLCG delivers to CERN required computing, storage and personnel resources, the SRC nodes pledges such resources to SKA every six months. Pledging is done via a Resource Board which has a representative from each country, appointed by each country's SKAO voting council member (i.e. to be appointed by VR after Swedish SKAO membership ratification). Delivery of pledged resources is carefully tracked by SRCNet management. Once the SKA is fully operational (from 2029), accumulated SRC deliveries are expected to be included in setting the observing time received by each country. Within OSO all personnel contributing to Module 5 are part of the OS unit. The reports from SRCNet management on deliveries versus pledges are made available to OSO line management so that OSO can take measures to ensure that OSO always delivers its pledged effort.

Qualifications of participants in infrastructure projects

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User support

User support is the core mission of modules 4 and 5 for OSO's users of mm/submm and cm/m wavelength data respectively.

Module 4: The Nordic ALMA regional centre (ARC) is one of 7 European ALMA regional centre nodes that provide ALMA user support in Europe. One of the primary functions of the Nordic ARC node is to provide face-to-face user support for data reduction of PI-led observations, as well as archive research. The initial step of assistance is offered during proposal preparation, during which ARC node staff provide consultations and detailed expert support on instrument setups. After a project is accepted, the ARC node assigns a dedicated contact scientist (CS) to assist the PI throughout all subsequent stages until data acquisition is complete. Upon data delivery, PIs, or their representatives (including PhD students), may request face-to-face support. This support is available at all levels for ALMA data reduction and analysis, either through visits to Onsala or through online consultation. Additionally, face-to-face support is increasingly being provided to support data archive mining.

A second primary task is the education and development of the ALMA user community at all levels. Prior to each annual ALMA deadline, the Nordic ARC node disseminates information on ALMA science possibilities to the Swedish astronomy community. Furthermore, the ARC node contributes to various interferometry schools. In preparation for the ALMA2030 upgrade, the Swedish community requires training on the utilization of the new ALMA data reduction software, RADPS.

A third support task is the development of advanced data reduction and analysis software for use by the ALMA community. In the past, this has included tools for model-fitting directly to ALMA visibility data and for 'stacking' data from multiple sources within a class of objects.

Module 5: The Swedish SKA Regional Centre (swe-SRC) is one of ~14 active regional centre nodes being developed to support future SKAO operations worldwide. It serves the Swedish user community in three capacities: providing data and user support to SKA and existing cm/m wave radio telescopes, testing algorithms for SKA-scale data analysis, and developing new data analysis tools for current and future facilities.

The SRC provides user support for existing and new users of PI-led projects on SKA precursor and pathfinder telescopes. Support and training cover proposal preparation to data reduction and imaging, tailored to the user's expertise level, from beginner to advanced. In the proposal stage, consultation and expert support on instrument setup and the development of a Data Management Plan (DMP) are provided. The DMP includes descriptions of existing community or bespoke pipelines/software for data reduction and an estimate of storage resources needed. After data acquisition, SRC supports data transfer, storage, compute hardware, and training or assistance with data reduction, both in-person and online.

During SKA science verification in 2027 (after commissioning in 2026), the swe-SRC will host data and provide processing resources as part of the global SRC Network. In 2028-2029, the first PI projects will be undertaken through "shared risk" observing. At this time, the swe-SRC will start supporting its community for SKAO observations and preparations.

The swe-SRC also provides resources and high-level computing support for Swedish teams participating in the SKA Science Data Challenges (SDC). As part of the "Science Delivery Stream" of the SRC Network, the best performing pipelines are incorporated into SKAO data analysis workflows. The SDC teams are domain experts, and the swe-SRC provides computing capacity and hardware support during the challenge. In the future, the SRC will also support archiving published data products from the SDCs.

Module Synergies: While there are significant differences in international organization and technical scope of the ARC and SRC nodes (in particular the SKA node has role hosting the SKA's globally distributed data archive and providing compute for the second tier of SKA data processing) there is also great scope for synergies especially for user support and tools. For instance, the swe-SRC (Module 5) via a project with ESO leads the development of a spectral line advanced data product pipeline for ALMA, in collaboration with the ARC Node (Module 4). This pipeline can also in the future be run within the SKA science platform at SRC nodes by SKA users.

Relation to other infrastructures

National Infrastructures - OSO works closely with the Chalmers node of the Swedish microfabrication facility MyFab which runs a large state of the art clean room at Chalmers. GARD's leading position in producing receivers for global radio astronomy projects is largely due to the synergy between the OSO and MyFab infrastructures.

OSO also has a linkage to the new NAISS infrastructure for supercomputing via the Chalmers e-commons infrastructure and its C3SE supercomputer centre - which is a node of NAISS - at Chalmers. As the work establishing an operational Swedish SKA computer support node advances OSO expects to form ever closer links to NAISS.

Finally, OSO has worked with members of the Swedish Institute for Solar Physics optimizing ALMA data reduction for solar observations and has also had some initial contacts with InfraVis concerning visualization of radio astronomy data.

International Infrastructures - Sweden is an ESO member giving full Swedish astronomer access to the world's largest ground-based optical and near-IR wavelength telescopes. Sweden is also an ESA member, providing access to the HST/JWST/Euclid space telescopes at optical/near-IR wavelengths and also access to other wavelengths only observable from space. OSO complements the wavelength access provided by ESO and ESA by providing/coordinating Swedish access to submm to metre wavelengths within the international radio astronomy landscape.

At mm/submm wavelengths OSO has many close connections with ESO, which in addition to its central role in optical/near-IR astronomy, is also the European coordinating partner within the global ALMA telescope collaboration. OSO, overseen by ESO, has built and continues to build receivers for ALMA. OSO also hosts the Nordic node of the European ALMA regional centre network, a network coordinated in Europe by ESO for providing ALMA data processing and user support.

At cm/m wavelengths OSO is building up its Swedish SKA Regional Centre node for SKA data support as part of the Swedish membership of the new SKAO intergovernmental organization. Sweden, via VR, pays annual fees to SKAO, to the LOFAR-ERIC/EVN and to JIV-ERIC, the latter two organizations providing long baselines and hence high spatial resolution imaging at metre and centimetre wavelengths respectively. As part of the Swedish membership of these ERICs OSO co-observes with its telescopes as an integral part of the LOFAR and EVN telescope networks.

Time plan

See following page for attachment

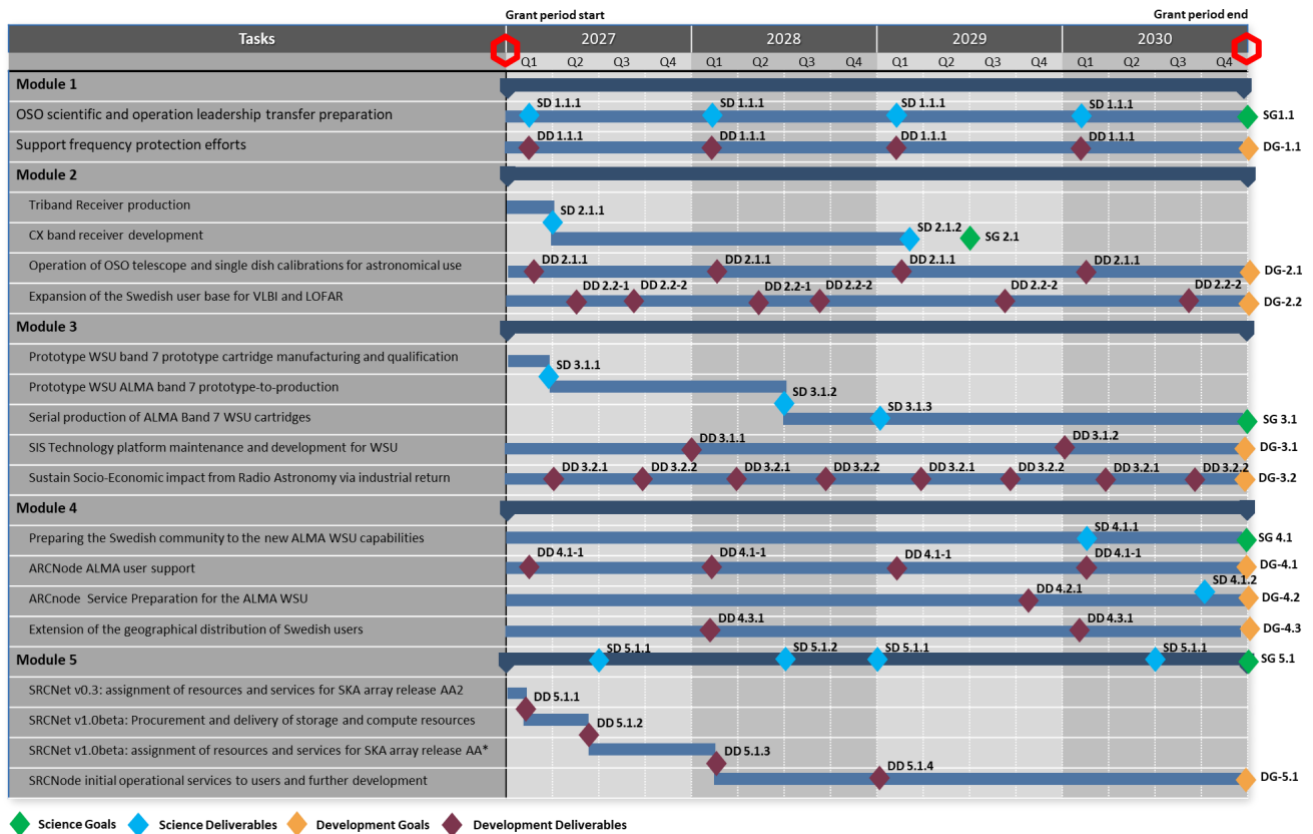


Table 1 – Gantt chart of goals and deliverables, see text below for details

Module 1 – Leadership and central functions - This module has one science goal **SG-1.1** - i.e. concerning OSO leadership continuity and succession - to ensure continuity of OSO scientific and operational leadership in preparation for a new OSO Director in place during the next but one funding period 2031-2034. The module also has one development goal **DG-1.1** – to support frequency protection efforts. Deliverables related to the above goals are;

-- **SD-1.1-1** – During the coming funding period the current Director distributes knowledge and leadership experience to deputy and other senior staff to ensure smooth succession/support of a future OSO Director. Updates on OSO’s organization will be presented in the OSO annual report – *Q1 every year*.

-- **DD 1.1-1** - Support continued funding for a common European radio astronomy frequency manager. OSO leadership engages nationally and internationally on the interference issue, with status of efforts reported in OSO’s annual reports- *Q1 every year*.

Module 2 – OSO Telescopes – This module has one science goal **SG-2.1** i.e. to build new receivers for the Onsala 20 m telescope i.e. a Tri-band receiver followed by a CX-Band receiver. This module has development goals; **DG-2.1** - To operate OSO telescopes within international networks and **DG-2.2** – To expand the Swedish user base for VLBI and LOFAR. Details of the associated deliverables relating to these goals are given below.

--**SD-2.1-1 - Triband Receiver Construction** - Assuming a positive proposal decision by end of 2025 components for the OSO 20 m telescope Triband receiver would be ordered immediately. Final detailed design of the receiver would occur during 2026-Q1, with construction of the receiver from 2026-Q2 through 2027-Q1. Following Chalmers university financial rules, the full cost of the receiver components would be charged when the receiver becomes operational i.e. to the 2027 OSO budget (given this is a national module costs will be shared 50% each by Chalmers/VR).

--**SD-2.1-2 -CX Band Receiver Construction** – Once the Triband project is completed, work will begin on a final design of a CX band (4.5 GHz–15 GHz) receiver. This matches SKA Band 5 in frequency range and will therefore maximally facilitate OSO 20 m telescope co-observing with the SKA. The receiver will be completed 2029-Q1 after which would become operational, and its component costs charged to 2029 budget (given this is national module costs will be shared 50% each by Chalmers/VR). This date is beyond the recommended 15 months after the start of the VR project for investments but is reasonable for scientific equipment that must be designed and built from components by OSO staff.

-- **DD-2.1-1** - Report OSO telescope use in every OSO annual report (Q1 each year) to monitor achievement of the goal of 90% successful observations. - *Every year Q1*

-- **DD-2.2-1** - Work within VLBI community for joint calls with other telescopes for transient follow up. OSO will propose such a new proposal mechanism during the EVN Board and JIVE council meetings 2027 Q2 and will follow up progress at scheduled meeting - 2028-Q2.

-- **DD-2.2-2** - Attend national/international space-weather meetings and make regular EISCAT-3D contacts. Delivery assumes at least one general space-weather meeting attended by OSO staff or joint OSO-EISCAT-3D meeting arranged per year.

Module 3 – ALMA Receivers – This module has two science goals and one development goal. Science goal **SG-3.1** is to deliver a full set of ALMA Band 7 Wideband Sensitivity Upgrade receiver cartridges in return for ALMA Guaranteed Time Observing to Swedish astronomers. The second Science goal is **SG-3.2** – Work for continued Socio-Economic impact from Radio Astronomy via industrial involvement in ALMA (and future SKA) project. The module Development goal is **DG-3.1** - Maintain and develop the GARD receiver technology platform in preparation for future ALMA (and mm-VLBI) receiver deliveries. Details and dates of deliverables for both goals are described below.

-- **SD-3.1-1** - Pass ESO (customer) PDR gate of demonstrating a prototype ALMA Band 7 WSU compliant receiver cartridge (based on results of APEX telescope on-sky demonstration) and begin production of first 6 ALMA band 7 receiver cartridges - end 2027-Q1,

-- **SD-3.1-2** - Pass ESO (customer) Manufacturing Readiness Review (MRR) project gate, start process of procuring materials and ramping-up series production - end 2028-Q2.

-- **SD-3.1-3** - Achieve full production rate of 2.5 Band 7 cartridges per month - end 2028-Q4. The above production rate will mean that full delivery of all Band 7 receivers will be in 2031, i.e. beyond the period of this VR grant. The negotiated Band 7 project agreement with ESO will specify direct funding of GARD personnel to complete delivery during this last year of production.

-- **SD-3.2-1** – Establish regular contacts with Big Science Sweden industrial liaison officer for Radio Astronomy before ESO/SKAO council meetings as part of Swedish preparation groups for these council meetings to facilitate information flow on industrial opportunities for ALMA and SKA.

-- **SD-3.2-2** – Work with Big Science Sweden(BiSS) in promoting the impact of academic – industrial cooperation in delivering technology to Big Science facilities that generate large industrial return for Sweden. Attend annual BiSS meeting and contribute to discussions on how to make this optimally effective in Sweden. .

---**DD-3.1-1** - Maintain collaborations with other instrumentation partners for adapting Band 7 SIS mixer technology for use for future ALMA Band 4 and Band 9 upgrade, to be achieved by arranging meetings with relevant instrumentation groups - 2027-Q4

-- **DD-3.1-2** - Demonstration of additional WSU compatible mixers for ALMA band 6 or 9, evolved from Band 7 technology. Mixers for these bands will be constructed and their full performance, i.e. bandwidth, noise, sideband rejection etc measured - end 2029-Q4.

Module 4 – ALMA Regional Centre This module has one science goal: **SG-4.1** - Position Swedish astronomers to fully exploit ALMA Wide Band Sensitivity data. There are three Development goals i.e. **DG-4.1** -. Support ALMA operations by performing data quality assessment and user software testing. **DG-4.2** - Prepare services for upgraded ALMA and **DG-4.3** - Expand the ALMA user base. Deliverables and their timing related to these goals are:

--**SD-4.1-1** --OSO ARC node staff to take part in end-to-end tests of new ALMA Wideband Sensitivity Upgrade (WSU) capabilities using wideband Band 3 and 6 receivers and new correlator capabilities - 2030-Q1

--**SD-4.1-2.** -- Support users of the first ALMA WSU projects – likely related to use of new correlator capabilities and wideband Band 3 and 6 receivers - 2030 – Q4

--**DG-4.1-1** - Ongoing user support. OSO ARC node supports its users and meet their science goals through contact scientist support, face-to-face support and community building events. OSO ARC node will provide full data and user support using for both ALMA legacy system and WSU. Measure progress via number of projects supported, as tracked in KPI data sent to VR – *Q1 every year*.

--**DG-4.2-1** -- Prepare services for upgraded ALMA. Implement new ALMA WSU pipeline software on OSO science cloud in preparation for SD-4.1-1 and SD4.1.2 above- 2029- Q4,

--**DG-4.3-1** - Expand ALMA user base - Organize training sessions at Swedish universities before major coordinated telescope calls like for ALMA-JWST and ALMA- ELT instruments. Exact timings uncertain but assume 2028-Q1 and 2020-Q1.

Module 5 – SKA Regional Centre

This module has one Science Goal **SG-5.1** – *To prepare Swedish scientists for first SKA data*, and one development goal, **SD-5.1** -*Swedish SRC node capacity development*. The former concerns education and training of the Swedish community to prepare SKA proposals and to become involved in Key Science Project (KSP) team formation. The second relates to the growth of the Swedish SRC node's capacity to supply compute, storage and services as part of the global SRCNet archiving and processing network, and following the development roadmap and specification for SRCNet releases, v0.3, v1.0beta etc. The timing of deliverables associated with these goals are described below.

-- **SD-5.1-1** -- Organize Sweden SKA Days (every 18 months) as part of series of national SKA science meetings- 2027-Q2 and approx. every 18 months thereafter.

-- **SD-5.1-2** -- Organize workshop on exploiting Swedish SRC node resources for analysing SKA data - 2028-Q2

--**DD-5.1-1** -- The SRC node delivers for SRCNet v0.3 its SRCNet assigned resources and services for SKA array release AA2 - 2027-Q1

--**DD-5.1-2** -- Procure and deliver compute and storage resources in preparation for SRCNet release v1.0beta – 2027-Q2

--**DD-5.1-3** -- The SRC node delivers SRCNet v1.0beta-assigned resources and services for supporting use of data from SKA array release AA* -- 2028 -Q1

--**DD-5.1-4** -- SRC node to provide early operation phase support to users (2029 and 2030) while continuing development toward full SKA AA4 deployment, likely 2031 and beyond -2029 -Q1

Long-term plan

OSO's long-term plans are closely connected to international community discussions on future radio astronomy and geoscience projects for the 2030's and beyond; as described below.

VLBI - To achieve unparalleled spatial resolution and sensitivity, full integration of VLBI telescopes with SKA-Mid is being actively pursued. Onsala like other VLBI sites is considering replacing an existing antenna with a new SKA or ngVLA (see below) dish to match the SKA 2070 lifetime. Even higher spatial resolution VLBI will be achieved using orbiting satellites, including projects for black hole imaging to which OSO's GARD group can supply their unique Band 6+7 mixer technology.

ALMA - The deployment of new broader (4 x) bandwidth receiver bands will continue through the 2030's with Europe expected to deliver a suite of Band 9 receivers after Band 7 is completed. GARD has already worked closely with NOVA in the Netherlands fabricating their Band 9 receiver mixer designs at the Chalmers Myfab facility. GARD is therefore well-positioned in partnership with NOVA to deliver future Band 9 receivers. For the longer-term ESO is considering, in discussion with its user community, its next major telescope project, with ALMA2040, having at least double the number of antennas as present ALMA, being one of the contenders.

SKA - After the initial SKA design is delivered numerous upgrades to SKA are possible in the 2030's including the addition of high frequency SKA Band 6 receivers; Swedish astronomers are already playing a leading role in advocating the science case for this upgrade. The OSO 20 m Triband receiver, which is part of this current proposal, acts in part as a prototype for this future SKA receiver.

Other projects under discussion include: **AtLAST**, a Norwegian-led 50 m diameter single dish survey telescope planned for the ALMA site, where GARD's Band 6 +7 mixers could be used as part of radio cameras; the **ngVLA** a US-led project to build an array in North America bridging between SKA and ALMA in frequency, and various proposed space missions, including a submm mission or an array for very long wavelength radio astronomy on the lunar far-side.

Geoscience - While this is not funded by VR, OSO's future plans for geoscience instrumentation development in collaboration with the Swedish land survey organization Lantmäteriet have many synergies with radio astronomy. Foremost in this regard are plans for a Nordic geodetic VLBI correlator and to observe dedicated space geodesy satellites.

Risk analysis

See following page for attachment

Risk analysis - In the following table, on a 1–3 scale, 1 is the lowest value/effect and 3 is the highest value/effect.

Risk number	Module number	Risk description	Probability (1–3)	Effect on the operation (1–3)	Assessed risk (high/medium/ low)	Mitigation	Assessed risk after mitigation (high/medium/ low)	Risk owner
1	All	Exchange rate variations – If OSO's annual funding from VR remains linked to cost in Kronor of the fees charged in Euros by international Radio Astronomy organizations (see Budget section of this proposal) this can lead to sharp year-on-year changes in annual funding payments to OSO from VR.	2	2	Medium	(A) OSO remains flexible in its project planning to react to variations in annual funding because of €/kr changes. (B) OSO seeks external projects (from EU etc) paid in Euros to reduce exposure to currency variations.	Low	OSO Management and Steering Committee.
2	All	Recruiting and retaining staff – Several critical functions at OSO depend on retaining/recruiting single skilled individuals. - with risks of single point failures.	2	2	Medium	(A) Further develop OSS as an attractive work environment connected to exciting local and international projects. (B) Argue within host university for improved career opportunities for infrastructure staff.	Medium	OSO Management and Steering Committee, Chalmers.
3	1-Leadership+ 2-OSO telescopes	Radio Interference – especially from satellite constellations - with consequence of increase noise in observations or even blocking observations at some observing frequencies.	2	2	Medium	(A) Continue to support international efforts to protect radio astronomy within regulatory framework and via cooperation with companies (SpaceX etc). (B) Ensure that next generation smart receivers (Triband, CX-band etc) are interference robust via using many sampling bits etc.	Low	OSO Management and Steering Committee.
4	2 -OSO Telescopes	Budget shortfall in delivering Triband and CX receivers – due to increased component costs, planning inefficiencies or reduced income due to currency variations (Risk 1)	1	1	low	(A) Continuous staff training on implementing optimum project management best practices. (B) In worst case (such as reduced income due to currency fluctuations) defer CX -Band to next funding cycle.	Low	OSO Management

5	3 – ALMA Receivers	Start of work on new Band 7 delivery delayed beyond January 2027 – due to late start of ESO selection process or due to establishing contract or consortium agreement. Potential issue of bridging funding needed for GARD till start.	2	2	Medium	(A) Create simple consortium agreement to reduce time between consortium choice to start of work. (B) OSO/GARD unit seeks other funding to bridge gap.	Low	OSO and GARD unit management
6	3– ALMA Receivers	Consortium led by OSO not selected to deliver new Band 7 – No science return to Sweden and future of OSO's GARD unit and Swedish mm-wave/THz instrumentation may be jeopardized.	1	3	Medium	(A) OSO/GARD delivers Band 7 prototype to APEX in 2026 fulfilling all upgrade specifications. (B) Obtain national funding (Risk 7) for Band 7 delivery making OSO led bid optimally attractive.	Medium	OSO and GARD unit management
7	3– ALMA Receivers	National funding not available for funding Band 7 construction – Increases chance that OSO led consortium is not selected (risk above) and no Band 7 science return to Sweden is obtained as well as irredeemable loss of mm-wave/THz instrumentation for Sweden and ALMA	2	3	High	(A) Explore all possible avenues i.e. other funding bodies, funded industrial partners etc for obtaining national funding for Band 7 work. (B) Negotiate with ESO about reducing GTO in return for replacing some national funding via direct ESO funding of critical OSO Band 7 work. Increases risk of OSO led consortium not being selected (Risk 6)	Medium	OSO and GARD unit management, OSO Steering Committee
8	4 – ALMA Regional Centre node	Delays in deployment of ALMA wideband Sensitivity Upgrade - ALMA remains in a hybrid state between old and new systems giving longer period of reduced ALMA output	1	1	Low	ARC node continues to support both legacy and new software to provide flexible support to users.	Low	OSO and ARC node management
9	5 – SKA Regional Centre node	Misalignment of SRCNet and SKA schedules – If SKA deployment is delayed (see Risk 10) then risk of under-use of deployed Swedish node compute/storage resources.	2	2	Medium	Closely follow progress of SKA council discussions on additional SKA construction funding (see Risk 10) and adapt SRC node investment and roll-out schedule accordingly.	Low	OSO Management and Steering Committee
10	5 – SKA Regional Centre node	Sweden does not contribute its share of required extra SKA construction funding - to secure SKA AA* array release – with consequences for Sweden's international reputation.	2	2	Medium	OSO supports case to government and its agencies for additional Swedish SKA funding for construction - via supplying arguments on science return and large current Swedish industrial return and future potential.	Medium	Swedish government and its agencies, Chalmers, OSO Management and Steering Committee

Details of risk management – for risks affecting budget

Risk 1 - Currency variations

Under current arrangements a +/-10% change in the €/kr exchange causes a +/- 2 Mkr/yr variation in OSO's income, so currency variations can have significant effects on OSO budget and its future planning. In addition to the specified mitigations in risk table above OSO can also adapt its spending profile to retain funds at the start of the four-year funding cycle to cover uncertainties due to currency variations for the last two years, and then be prepared with different spending plans based on different currency impacts on OSO budget during last years of funding cycle.

Risk 4- Cost overruns on new Onsala receiver bands.

The main project risk is that construction of these receivers takes longer than expected, but this will not lead to a direct increase in costs. There is a risk however that if CX-band is not operational by the end of the coming funding period then the cost of its components cannot be taken on the coming grant; with no assurance that VR will approve these costs for the following grant period. At the end of the Triband receiver project OSO must assess that it has both the financial resources (in the face of currency variations), and the needed personnel resources, to complete the project within the next funding period. If the risk of this not happening is too high then OSO should defer this project to the next funding cycle and include a request for funding for this receiver in its 2029 proposal.

Risk 5 - Delay of start of ALMA Band 7 receiver construction project beyond early 2027

Potential alternative bridging funding for GARD includes seeking further ESO ALMA development projects (maximum 1- 2 Mkr/yr) for future Band 9 or Band 4 ALMA development. Also, GARD can seek contracts from member stations of the Event Horizon Telescope (EHT) network for black hole imaging to deliver Band 7 mixers or full receivers.

Risk 6 - The consortium led by OSO does not get awarded the WSU Band 7 construction contract

The OSO GARD unit works deliver as early as possible (goal 2026) to the APEX single dish telescope in Chile a Band 7 prototype fulfilling all ALMA WSU specifications - so that this receiver prototype performance can be fully demonstrated on-sky before ESO begins the Band 7 bid proposal evaluation process (scheduled to begin mid 2026).

VR provides the requested funding to this module, greatly increasing the chance that the Swedish led consortium is chosen for delivery based on value-for-money. as well as the superior performance that we are confident the OSO/GARD led bid can offer.

Submit ESO ALMA development proposals to work on Band 9 and development projects. GARD seeks work from member stations of the Event Horizon Telescope (EHT) network for black hole imaging to deliver Band 7 mixers or full receivers.

All parties to discuss possibilities to retain GARD's competence till the next funding opportunity, including funding from VR to work on longer term receiver development for ALMA (and SKA).

Risk 7 – National funding not available to support OSO Band 7 delivery

-Investigate all possible avenues to secure national funding. This includes investigating Swedish industrial funding to a Swedish company for part of Band 7 production (for instance a company that has delivered to SKA). Funding a company to do part of the work which GARD manages could secure ALMA Guaranteed Time Observing return to Sweden but may not provide sufficient funding to OSO/GARD to allow the retention of all key GARD competence and hence is likely to be an irremediable loss of mm-Wave and THz instrumentation for radioastronomy. Submitting to ESO a Band WSU 7 bid with reduced in-kind contribution (VR financing) replaced by direct funding from ESO to GARD makes the bid much less attractive in terms of value-for money for ESO and also less attractive for Sweden, since it reduces the GTO on one of the most attractive bands of ALMA and increases (risk 6 above) and might even scare off potential consortium partners.

Ensuring research-supporting activities

Within Radio Astronomy, as in many scientific disciplines, there is a very clear distinction between research *using* an infrastructure and R&D *developing* it.

Research using the Infrastructure: A VR-funded infrastructure's goal is to support its user community, so internal personnel effort funded for OSO infrastructure duties clearly cannot be used for astronomy research. Most OSO staff are technicians/research engineers without astronomy research training, so for these staff no issue arises. OSO also employs some PhD-trained astronomers as telescope/user support scientists, allocating 30% of their time (Chalmers-funded, outside the national infrastructure contribution) for research. This time is typically spent applying for observations on radio telescopes, reducing data, and publishing results. Offering support astronomers research time is standard at astronomy observatories worldwide. For these staff OSO strictly enforces a 70/30 division between infrastructure duties and research which is monitored through regular one-on-one meetings with line managers.

Research and Development to improve the infrastructure: The second category of effort, R&D to develop the infrastructure, occurs within OSO's GARD and TSG units, with this development effort being key to OSO's success. In radio astronomy, advanced research instrumentation, such as quantum-limited receivers, is highly specialized and must be designed for each specific application, for instance for each ALMA frequency band. Infrastructure funding enables advancing receiver technology through medium and high TRL levels culminating in building final operational systems. This development is vital for improving radio telescope sensitivity and hence their productivity but is currently not possible to fund through general academic grants.

Teaching: For the few OSO staff who teach, teaching time is tracked hourly, and the university accounting system prevents double charging this time to the infrastructure.

Budget

Budget for the infrastructure

Filename: Budgetmall-OSO-v20.xlsx - **Filesize:** 611 kB

[Budgetmall-OSO-v20.xlsx](#)

Amount applied for from the Swedish Research Council

Amount applied for from the Swedish Research Council - 2026		2027	2028	2029	2030
1 Chalmers	0	0 52,151,000	34,713,000	37,350,000	36,126,000 160,340
Total	0	52,151,000	34,713,000	37,350,000	36,126,000 160,340

Total budget

Specified costs	2026	2027	2028	2029	2030
1 Running costs	0	52,151,000	34,713,000	37,350,000	36,126,000
2 Subtotal	0	52,151,000	34,713,000	37,350,000	36,126,000
3 Indirect costs	0	0	0	0	0
4 Total project cost	0	52,151,000	34,713,000	37,350,000	36,126,000
Total, applied		Other costs		Total cost	
1	160,340,000	0		160,340,000	
2	160,340,000	0		160,340,000	
3	0	0		0	
4	160,340,000	0		160,340,000	

Adjustement to budget changes

The total OSO budget request is **160.3 Mkr** or **40.1 Mkr/yr**. Adding international fees of **20.5 Mkr/yr** (see budget explanation) gives a radio astronomy (RA) packet cost of **60.6 Mkr/yr**. Components of this cost to VR are given below, followed by prioritization comments. Complementing the VR contribution, in addition to providing matching funds, Chalmers also funds **5.9 Mkr/yr** for the personal science time of OSO's twelve support scientists (see Leadership section) without which OSO would not have critical staff to function.

(A) National module base cost i.e. Module 1 - Leadership, plus Module 2 - OSO telescopes without Triband and CX band receivers, plus Module 4 -ALMA Regional Centre without computer upgrade has VR cost **15.8 Mkr/yr**. Adding VR's international fees gives a RA package cost of **36.3 Mkr/yr**.

(B) Module 3 - ALMA receivers - ALMA Band 7 receiver delivery - bringing back valuable ALMA observing time to Sweden - costs **11.2 Mkr/kr**. Combining with A gives total RA packet cost **47.5 Mkr/yr**, or an increase of 9.5 Mkr/yr compared to today's total RA cost of 38 Mkr/yr. Note Risks 5,6,7 in the Risk Table section relating to this module.

(C) Module 5 - SKA Regional Centre - minimum funding - which maintains current compute/storage, current staff plus one new critical hire costs **6.6 Mkr/yr**. This funding is essential so that Swedish scientists have access to the first SKA data; without this funding the work done in recent years establishing the Swedish SRC node would be wasted. Funding this plus A and B requires RA packet funding of **54.1 Mkr/yr** or an increase of 16.1Mkr/yr compared to today.

(D) Module 5 - SKA Regional Centre - full funding - meeting SRCNet roadmap/ALMA upgrade requirements, needs a significant investment in new hardware in 2027 (see Data Handling section) plus an additional hire, together costing **4.7 Mkr/yr** for a total RA package cost **58.8 Mkr/yr**.

(E) Triband and CX-band 20 m telescope receiver costs added to Module 2 spread over 4 yrs give a total RA package cost of **60.6 Mkr/yr**.

Items A, B and C above are equally vital for meeting Sweden's commitments to international projects and retaining key competence at OSO. Not funding these three items in full would risk irreparable damage to OSO's continued viability in critical areas (i.e. VLBI, ARC node, GARD and SRC node). Not funding budget points D and E also risks seriously damaging science delivery to Swedish users and Sweden's reputation as a full partner of SKA and international VLBI respectively.

Added value of grant from the Swedish Research Council

The recent (2023) international evaluation of Swedish physics noted Sweden's world class astronomy research; a major success factor for this being Sweden's excellent telescope access. As part of provision for radio wavelengths Sweden is a member of the intergovernmental organizations, ESO and SKAO, which run the ALMA (submm/mm) and SKA (cm/m) telescopes. OSO is a key construction partner for both telescopes. Sweden is also in two European Research Infrastructure Consortia (ERICs), JIV-ERIC (mm, cm) and LOFAR-ERIC (m wavelength) that run long baseline radio telescope networks which include OSO's telescopes.

OSO's national role in radio astronomy, and the added value it provides in return for VR funding, is to maximize Sweden's scientific and other return from the above international radio astronomy projects which VR pays for. The science return from OSO's ALMA construction and user support activities is well demonstrated, with 25% of Swedish astronomers being ALMA users (see *Current Operation* section). Additionally Swedish astronomers are authors on 12.5% of all ALMA papers, even though, through ESO, Sweden contributes only ~1% of ALMA's global running costs. This success can be directly attributed to the efforts at OSO.

Sweden's science return from SKA, enabled by the build-up of OSO's data/user support node, is expected to be just as large, especially given the wide interest across the country in SKA's scientific potential (see *Expected User section*). In parallel ALMA is being upgraded to at least double its scientific throughput, ameliorating its biggest limit on science return which is its huge (8.4) oversubscription rate. This issue is reduced further if Swedish astronomers get ALMA Guaranteed Time Observing in return for OSO supplying new Band 7 receivers.

Additional national added value comes via the contracts to Swedish industry for ALMA and SKA construction generated via OSO's national role (see *Socio-economic impact* section). For SKA alone this contract return, to date (300 Mkr), is larger than Sweden's total contribution to SKA in combined construction capital costs and the first ten-years of its operating costs drawn from the radio-packet for radio astronomy operations.

There is also the added value of OSO providing vital national services for geodesy (see *Socio-economic impact* section) which can be done at low cost (11 Mkr/yr from Läntmateriet outside the attached radio astronomy budget) via synergy with OSO's radio astronomy role.

User fees

User fees are rarely charged in the field of astronomy. The telescopes used by astronomers are extremely expensive to build and run and a system in which researchers sought funding for telescope time fees as part of their grant applications would not be practical.

If such a system with user fees were to be implemented, then which researchers got observing time among the global community would depend more on the policies of their national funding agencies toward funding large telescopes through research grants than the scientific quality of the proposal.

It is more effective scientifically for national research councils to collectively finance large telescope infrastructures directly and then for these infrastructures to allocate telescope observing time based only on the quality of the scientific proposals they receive from the (usually) multi-national groups of researchers who apply and compete for observing time.

Justification of the budget applied for

1) Total costs of Radio Astronomy to VR - Currently OSO's funding is organized within the frame of a 'Radio Astronomy Package', funded today at a level of 38 Mkr/yr, out of which is drawn the fees to the international radio astronomy organizations with Swedish membership, with the remaining annual funds paid to OSO for its operations (so OSO absorbs exchange rate fluctuations). It is assumed that a similar arrangement will apply during the next funding period 2027-2030. Assuming VR agrees to fund this proposal's requested contribution to OSO in full, the revised radio astronomy packet funding is expected to equal this requested OSO amount plus VR's estimate of the future kronor annual fees to international radio astronomy organizations.

The annual membership fees that VR will pay directly to the JIV-ERIC and LOFAR-ERIC are expected in 2027 to be equal or close to today's levels of 0.190 M€/yr and 0.095 M€/yr respectively. As part of the commitment to Swedish SKA funding agreed between Chalmers and SKAO the Swedish share of SKA operations funding in 2027 (through to 2030) is 1.5 M€/yr, this figure will be formally confirmed by VR when Swedish membership of SKA begins in mid-2025. Summing together these three annual fees gives a total of 1.785 M€/yr. Assuming today's exchange rate of 11.5 kr/€ this total equals 20.53 Mr/yr. Combining this with the OSO request from VR in this proposal of 40.1 Mkr/yr, the new radio astronomy package annual level would then be $40.1 + 20.5 = 60.6$ Mkr/yr, compared to today total package value of 38 Mkr/yr this would be an increase of 22.6Mkr/yr.

2) Effects of inflation and kronor devaluation - As itemized in the *budget adjustments* section a significant increase in OSO funding is needed in order to retain OSO's current capabilities and not lose key competence built up over many decades. The fundamental reason is the flat funding that OSO has received from VR in kronor over a long period. Funding from VR for OSO plus international radio astronomy fees has been at a level of 38 Mkr/yr since 2013, with a temporary reduction for 2016 and 2017 due to reduced VR-RFI income, that was then restored to just below 38 Mkr/yr from 2018 onward. OSO was due to submit a new proposal for its operations in 2021 but when the proposal to VR to join SKA was successful in 2019 the funding level for the 'radio astronomy package' was continued at the same level of 38 Mkr/yr through to the end of 2026. Assuming 2%/yr inflation in 2025 and 2026 the change in the Swedish consumer price index from the start of 2018 to end of 2026 is estimated to be 1.32 while VR funding remained constant.

A condition of Sweden joining the SKAO was that the annual operating costs would be charged to the Swedish operations budget for radio astronomy (i.e. the 'radio astronomy package' see point 1 above) out of which OSO's budget is also drawn. OSO has reorganized its activities to make budget room for SKA fees, by leaving the APEX single dish project (despite it remaining scientifically productive) saving 7 Mkr/yr and finding an alternative financier for OSO's geoscience activities in Lantmäteriet, the Swedish land survey organization, bringing in 11 Mkr/yr. These two actions in combination more than cover the SKA fees and would also have covered SKA Regional Centre node costs if the Euro/Kronor exchange rate had stayed at its 2016-2019 level of 10kr/€ as compared to today's 11.5kr/€.

OSO has taken measures to reorganize its activities to make room for the great opportunities for Swedish astronomy (and Swedish industry) that joining SKAO affords, fully realizing that new additions to VR's budget could mean reductions elsewhere in radio astronomy costs. It is extremely challenging however to do this against a background of decreasing real income over more than a decade. OSO's budget, with stable FTE count, has been carefully managed to be in balance integrated over the 9 year funding period 2018 - 2026 of OSO's current extended VR contract, but by 2026 due to accumulated reduced real income effects OSO's radio astronomy result is projected to be -13 Mkr/yr with projected average losses -16 Mkr/yr during the next funding period. Hence at minimum, i.e. without expansions to meet SKA data requirements, items A, B and C of the 'Adjustment to Budget' need to be funded from 2027 onward. Otherwise, OSO faces losing key competence, built up over many years, and thereby also Swedish leadership in the field.

Consortium, and ethical and socio-economic considerations

Consortium – participating organisations

OSO is not run as a consortium of universities in Sweden but is operated by a single host university i.e. Chalmers University of Technology. This structure reflects the fact that Onsala Space Observatory (OSO), founded as a radio astronomy observatory by Chalmers in 1949, and which became a national facility in 1990, is the sole site in Sweden at which radio telescopes are operated. Given radio telescopes are expensive it is rational to locate this equipment at one site and make them available to all Swedish researchers. It is also efficient, given that OSO has a major national role for providing instrumentation (i.e. receivers) to international radio telescopes, that this work is carried out at one node, and likewise that national data processing and user support is delivered by a single critical mass of personnel and hardware. While OSO is an infrastructure hosted by a single Swedish university, its leadership structure ensures that OSO works for the benefit of all Swedish researchers (Chalmers has only one member on its Steering Committee; the other members are from other universities in Sweden or are international members).

Consortium – support letters

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Ethical considerations

Astronomy does not involve any ethical issues related to human or animal trials or deal with personal data. OSO's radio telescopes are passive instruments that do not transmit but only gather extremely weak radio signals from space and hence their operation has no direct effects on human health or the environment. OSO does strongly support the actions taken by the international infrastructures to ensure an ethical use of the land the telescopes are built on. For example, the SKAO recognises and acknowledges the Indigenous peoples and cultures that have traditionally lived on the lands on which the SKAO facilities are located and the SKAO is involved in several initiatives supporting the indigenous population.

Although being part of international telescope networks requires many international meetings OSO is committed to reduce the environmental impact of international travel by choosing, when possible, to participate remotely. This policy is also strongly encouraged for our international partners.

Additionally, OSO is also strongly committed to push for detailed plans for reduced and/or green energy consumption in the operation of international telescopes.

Data collected by OSO's telescopes is not of any significant defence or security importance for satellite tracking or other purposes given it covers a very small beam area on the sky and such raw data can only be accessed by a few authorized people.

Socio-economic impact

While OSO's main purpose is supporting its users in conducting basic research, the infrastructure contributes socio-economic impact in several ways. Its design of advanced radio telescope components has resulted in a large return on investment including to Swedish companies. Its extensive outreach effort to young people contributes to the government's STEM strategy. Lastly, Onsala's geoscience activities relate to sustainability issues in several ways.

Innovation and Industrial Return: OSO has developed critical parts of the ALMA and SKA radio telescopes, generating financial return to Sweden while optimizing telescope performance. For ALMA, OSO's GARD group has since 2009 received 145 Mkr for receiver development and construction. Omnisys AB and Low Noise Factory AB have had or currently have contracts worth together 104 Mkr. For SKA, awarded contracts total 31 M€ (356 Mkr) compared to Sweden's 175 Mkr contribution to construction costs. The industrial return ratio relative to the minimum guaranteed level of 10 M€ is 3.1, which **is the largest among all SKA countries**. Beyond the direct financial returns the indirect economic impacts of the competence developed at companies from radio astronomy is considerable.

Swedish contributions to SKA include SKA-mid Band 1 receivers, designed and prototyped by OSO, and Band 1+2+3 digitizers supplied by Qamcom AB in collaboration with OSO. Low Noise Factory AB is supplying SKA Band 1 Low Noise Amplifiers and is the preferred supplier for Band 5 amplifiers. The RISE standards laboratory in Borås is currently the only certified European facility for testing equipment to meet SKA's radio frequency interference (EMC) standards. Ongoing procurements involving Swedish companies include Band 4+5 digitizers and Band 5 receivers, with decisions expected by July 2025.

Sweden's success in industrial return from ALMA and SKA stems from OSO's receiver design and prototyping expertise. Since 2018, Big Science Sweden has also efficiently connected OSO with industry. OSO's longstanding role as a national infrastructure has impacted the West Sweden economy within radio technology, not least through training skilled individuals. This has led to the creation of spin-off companies such as Omnisys AB (1992) and Low Noise Factory AB (2005), both rooted in radio astronomy.

Public Outreach and Education: Astronomy captivates the public, schools, and media. Onsala Space Observatory plays a central role in Chalmers' public engagement and education initiatives, particularly with the local community, regional schools, and national media. OSO offers guided tours, public events, and activities funded by Chalmers. The observatory's new visitor centre, inaugurated in 2022 and funded (at a cost of 30 Mkr) by Chalmers with Hasselblad Foundation support for its exhibition, provides interactive experiences with working radio telescopes and instruments. Outreach activities involve Ph.D. students and undergraduates, enhancing societal impact and learners' science capital. Chalmers is increasing investment in outreach staffing from 1.6 FTE to 2.1 FTE starting February 2025. The SALSA 2.3-meter telescopes are used for student training, school projects, and online global access. OSO continues to develop opportunities for public engagement, connecting with international facilities like ALMA, SKA, and Geodetic-VLBI and collaborating with international partners such as JIV-ERIC and SKAO.

Sustainability Goals via Geoscience Observations: Geodetic VLBI (Very Long Baseline Interferometry), in which OSO plays a leading role, is a core technique for defining the terrestrial reference frame, Earth orientation and rotation, and the celestial reference frame, which are foundational for global geodesy. These reference frames underpin precise positioning systems, satellite operations and climate monitoring, all critical for sustainable development, as well as for navigation. The recent establishment of the UN Global Geodetic Centre of Excellence (UN-GGCE), in which OSO is a partner, marks a milestone in advancing global geodetic infrastructure. By ensuring high-accuracy geodetic data and coordinating international efforts, the UN-GGCE supports the global geodetic supply chain fostering collaboration among nations to meet scientific, technological, and societal needs. This initiative aligns with UN sustainability goals by enabling better disaster management, monitoring sea-level rise, and improving agricultural planning.

Data management and e-infrastructure

Generation and handling of data

See following page for attachment

The data flow of the three proposal modules that produce/handle data are briefly described below. For Module 2 (OSO telescopes) the main requirement is to transmit large data flows from OSO. In contrast Modules 4 (ARC node) and Module 5 (SRC node) involve handling large volumes of incoming data, storing this data and applying computing resources to generate advanced data products. The detailed hardware resources required to support these functions are described in the following *Technical Solutions* section.

Module 2 – OSO Telescopes – The radio telescopes operating at Onsala as part of international arrays produce raw data which must be transmitted to international correlator centres to be combined with data from other telescopes. Analogue voltages measured by Onsala telescopes are first digitally sampled at Nyquist rates and then sent over data links to correlator centres. In the coming years OSO's upgraded LOFAR station will generate 6 Gbps while its 20 m, 25 m and OTT geodetic telescopes will each generate up to 64 Gbps. Onsala has a dedicated fibre link from the observatory which makes a local connection to the Swedish academic data network (SUNET) backbone. OSO will for the coming funding period rent two 100 Gbps connections from the Swedish academic network service provider SUNET, one for Geoscience and the other for Astronomy use. Since the 20 m and 25 m telescopes will not transmit data at the same time this arrangement will be sufficient. After correlation raw telescope data is deleted and only the correlation products, or *visibilities*, are permanently archived. These data sets are relatively small, amounting, for a typical 12 hr observation, to only 0.1 - 1 TB. Usually, the proposing team has exclusive access to these data for a proprietary period of one year, after which the data is accessible by anyone. *Since this data (like that produced by ALMA or SKA below) has no personal information and has no commercial value* no difficulties arise with such open data. FAIR principles are always applied to the archived data to maximize its legacy value. The final step in the data processing is the conversion of visibilities into radio sky images. This step is implemented via processing pipelines, automatically running at the correlators, with the outputs covered by the same access rules as for visibilities. It is also possible to download project visibilities to OSO where images can be produced using non-standard pipeline parameters, to allow for instance a slightly different spatial resolution.

Module 4 – ALMA Regional Centre (ARC) Node – Raw data from the ALMA antennas are combined locally at the ALMA correlator where visibilities are produced. Initial quality assessment of the data is also performed automatically at the Operations Support Facility (OSF) in Chile. For most projects, a final quality assessment is performed during pipeline processing in Chile or at the main ARC coordinating node in each of ALMA's three regions (Europe, North America and East Asia). A small subset of projects, for example polarisation or VLBI observations, require manual quality assessment and pipeline processing. For such projects supported by the Onsala ARC node, local computing resources are used. All ALMA projects are then injected in the ALMA science archive, which is a fully distributed database and data storage-system, with operational parts at the OSF, the ALMA Santiago Central office (SCO) and the European, North American and East-Asian ARCs. The ALMA archive operates following the FAIR principles. From there, the data is distributed to the principle investigators (PIs). For advanced data processing, Swedish PIs or their representatives visit the Onsala ARC node, who can both run a local copy of the ALMA pipeline as well as support more specialised data processing. Following the ALMA Wideband Sensitivity Upgrade (WSU), the computing requirements for the processing of ALMA data will change radically. In the initial phases, the ARC nodes will likely need to manually process the first WSU data sets of their respective communities.

Module 5 – SKA Regional Centre Node – By the end of this decade SKA is expected to become one of the world's most prodigious science facilities in terms of its data production and computational requirements. A layered global architecture for data delivery has been adopted by the SKA project (see Fig. 1). Sampled data from SKA dishes or stations is first correlated locally to produce visibilities. In general, these visibilities are too large to be permanently stored, instead they are immediately converted into images and other Observatory Data Products (ODPs) by dedicated Science Data Processors (SDPs) located respectively in Perth and Cape Town. Although ODPs will be archived at the SDPs for data backup security purposes these data repositories will not be directly accessible by users. For this ODPs will be distributed onward to SKA Regional Centre (SRC) network nodes sites located in each SKA member country. These nodes also contain computational

resources to convert ODP's into Advanced Data Products (ADPs) which are also archived at the SRC nodes

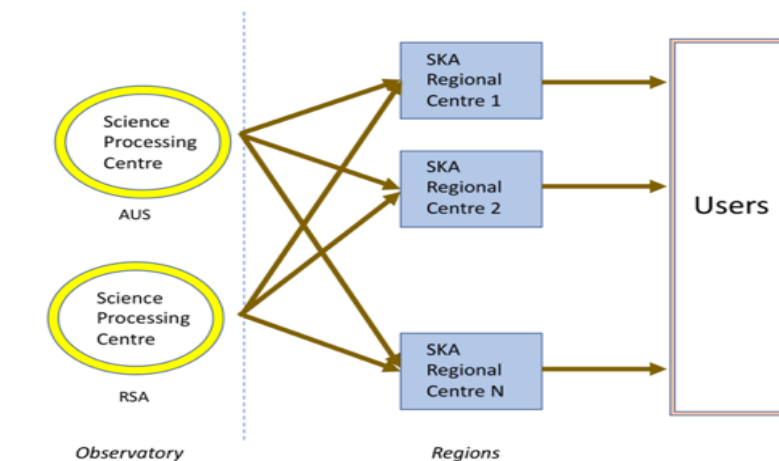


Figure 1- Illustration of SKA data flow.

The SRC Network will use a common global gateway so users can access their data. The current SRCNet roadmap defines a set of version releases for the rollout of the network defining the hardware capacity and services a participating node should have at each release. The first SRCNet release v0.1 started at the beginning of 2025 and will run all year, this first prototype will be a first test of 8 SRC nodes working together, with compute and storage specified at only 2% of the level required to serve the final SKA as designed. SRCNet versions 0.2 and 0.3 should be deployed by the start of 2026 and 2027 and will have respectively 10% and 15% of full capacity. Version 0.3, will be the first to support user commissioning observations of SKA. Version 1.0 beta is due to be ready by the start of 2028. This SRCNet deployment is expected to be enough to serve operations of the SKA AA* array, which is largest version of SKA funded by SKA members for deployment this decade. A further expansion of the SKA and SRCNet is expected in the 2030's when the capacity of SRCNet will likely need to be doubled.

OSO Science Cloud - Table 1 shows the planned past, current and future capacity of a Swedish Science cloud dimensioned to serve both future SKA and ALMA needs. More details are given in the following *Technical Solutions* section.

	2024	2025	2026	2027	2028	2029	2030
SRC CPU Compute (TFLOP)	3	79	79	79	260	260	260
ARC CPU Compute (TFLOP)	3	9	9	9	29	29	29
Total CPU Compute (TFLOP)	6	88	88	88	289	289	289
				0			
SRC Storage (TB)	792	2 970	2 970	2 970	7 871	7 871	7 871
ARC Storage (TB)	88	330	330	330	875	875	875
Total Storage (TB)	880	3 300	3 300	3 300	8 745	8 745	8 745

Table 1 –OSO Science Cloud capacity versus time

Technical solutions

For OSO telescopes in Module 2, for sending data to VLBI correlators, two 100 Gbps light path links are required. The combined storage and compute needs for modules 4 and 5 are set by the needs of the ALMA ARC and Swedish SRC nodes. An 'OSO Science Cloud' is being deployed to serve these needs based on a cloud computing solution which OSO is developing in partnership with Chalmers e-Commons, the Chalmers infrastructure for high performance computing that also provides the NAISS node C3SE. The level of cloud computing required for the SRC node is currently not available through NAISS.

This initial local cloud solution will provide a testbed for establishing a Swedish node in the basic system that SRCNet will deploy by 2027 to give astronomers access to the first SKA commissioning data. Swedish SRC node hardware needs are derived from the requirement that each national SRC node should provide a share of total SRCNet compute and storage equal its SKA share (in Sweden's case 1.5%). Analysis of ALMA data needs during WSU ramp-up and full operations indicate total data requirements that are 10% of those for the Swedish SRCNet, with this additional ALMA requirement being adopted for dimensioning the OSO Science cloud.

In 2025 a significant investment in compute and storage hardware establishing the OSO science cloud, costing 6.5 Mkr, is being made. This initial investment allows the Swedish SRC node to meet its SRCNet v0.3 release requirements and ALMA WSU needs through the end of 2027. The above hardware has a service lifetime of 6 years and so can also be used toward supporting SRCNet v1.0 beta from 2028 onward so that will serve the AA* SKA array release plus ALMA WSU during 2028-2030. However, as indicated by Table 1 in the previous section, a purchase of 200 TFLOPS and 5.45 PB is required in 2027 to meet expectations of Sweden's v1.0 beta plus ALMA needs. Assuming all compute is CPU (not GPU) and storage is 90%/10% HDD/SSD then based on the current ongoing procurement the total investment cost, given in the excel budget, is 13.6 Mkr, with running costs estimated at 1 Mkr/yr, and both capital and operations costs shared 10%/90% between Modules 4 and 5. The core software for both ALMA and SKA data processing is being developed collectively within the international ARC node and SRC node networks, with this software being freely shared between all nodes. Specialized software being developed by the OSO SRC and ARC nodes is described in the next section.

User support and user tools for e-infrastructure

The ALMA ARC node (Module 4) allows users to re-run standard calibration and imaging pipelines with special settings, provides manual calibration and imaging assistance, and educates the community about interferometry, data reduction and software (CASA package). The ARC node also develops specialist data analysis software to fit models to ALMA visibility data. The node has been developing ML methods to mine the ALMA archive for images that show specific structures like disks or jets in protostars. For ALMA WSU, a new data handling software package (RADPS) will replace the existing CASA software. A major focus of the ALMA ARC node in the preparation for WSU will be to train the entire Swedish community in the use of RADPS.

For the swe-SRC node (Module 5) many different user tools are planned to be developed and deployed for SKA user groups including standard data reduction pipelines, data visualization (including possible Virtual Reality tools) and source finding tools based on ML/AI methods. Related to the latter OSO recently competed in Science Data Challenge 2 for finding spectral line sources in simulated SKA data cubes, coming in a very close second place. This code is now being applied to real SKA precursor telescope data. The SRC node will during 2025/2026 enter data challenge 4 to create ML software to find polarized sources in cubes.

In line with open science principles software/pipelines that use SRCNet processing resources will become available to the community. Tools and support methods will continue to be developed, deployed, and operated through the commissioning, science verification, early science, and the beginning of large legacy survey stages of the SKA telescopes (through 2030). Starting in 2027, users will be able to access SKA data by connecting to the SRCNet Science Platform (v0.3) which will host software necessary for advanced data processing, analysis, modeling, and visualization. In the period from 2027 to 2030, the resources of SRCNet will double, and software will continue to be rolled out as it is developed.

There is great scope for exploiting synergies in analysis tools for use on both ALMA and SKA. As an example there is currently an ongoing development project at OSO funded by ESO, to adapt for ALMA use, a tool for analyzing 3D position-position-velocity data cubes developed originally for centimetre wavelength spectral line data. Very likely that tool will likely to be further developed and eventually used for SKA.

Current operation

The questions under this tab shall only be answered for applications what wholly or partly constitute a continuation of an operation with an ongoing grant to research infrastructure of national interest from the Swedish Research Council.

Adherence to the time plan for the current grant period

OSO last applied to VR for funding its activities in 2017 resulting in funding 2018 -2021. In 2019 a proposal for Swedish SKA participation resulted in VR forming a 'radio astronomy packet' for OSO plus SKA annual operations costs for 2021-2026. This replacement contract states that the 'OSO Strategy 2020- 2030' submitted to VR in 2019 (available at the OSO website) defines the current OSO work programme. We interpret the period of planned activities to report on since the 'previously approved application' to be those since 2017.

-Technical Goals-

APEX Receivers - A new Band 7 receiver (with 8 GHz bandwidth, 2x current ALMA, 0.5x ALMA upgrade spec) was delivered to APEX in 2019 according to schedule.

ALMA Receivers - The GARD group completed its delivery of a full set of Band 5 receivers to ALMA during 2018 as planned. During 2019-2023 GARD as planned contributed significantly to the design phase and prototyping of the new ALMA Band 2 receiver for deployment. Since the end of that project the GARD group, has as defined in the OSO strategy, been maturing technology for 16 GHz bandwidth Band 7 receivers for the ALMA Wideband Sensitivity Upgrade.

SKA Receivers and Digitizers - The OSO SKA Band 1 receiver prototype was completed by OSO's TSG group on schedule in 2018 and delivered to South Africa for testing. During 2023 a large contract was awarded to the Swedish company Omnisys AB for Band 1 full production. In the same year, in close collaboration with experts on radio astronomy digital receivers at OSO, a large contract was finalized by Qamcom AB to deliver SKA Band 1+2-3 digitizers.

LOFAR 2.0 upgrade - The planned upgrade of OSO's LOFAR station to its new more capable 2.0 standard originally scheduled for 2021 has, beyond OSO's control, been much delayed due to design. cost and procurement issues related to the pandemic and then completing final technical design.

New VLBI Receivers - The decadal strategy proposed that two new receivers would be built for OSO's 20 m telescope, namely a Triband and a wideband CX- band receiver. These receivers have not been constructed due to lack of funding due to the high Euro/Kronor exchange rate which has increased the Swedish Kronor costs for SKA operations, which under the radio astronomy packet then reduced VR funding to OSO.

- Programmatic Goals -

New funder for Geoscience - A major goal stated in the OSO strategy document was to transfer funding responsibility for OSO's geoscience activities to the Swedish national land survey organization - Lantmäteriet - this transfer was achieved in 2021 with an associated funding commitment to OSO of 11 Mkr/yr.

Swedish SKA Regional Centre (SRC) - The Swedish SRC node was established on schedule in 2023 with 3 persons (1.9 FTE) hired. Providing an SRC node is expected of every SKA member and is essential for Swedish users to access SKA data. The node also fulfils user wishes, as communicated in user surveys, to support SKA precursor telescopes in preparation for SKA.

Fulfilment of remaining goals for the current grant period

Following OSO's Strategy document 2020-2030, which defines current OSO's work programme, OSO has the following main goals to complete during the last two years (2025 and 2026) of its current VR grant.

Swedish SKA Regional Centre (SRC) - OSO will in 2025 install a significant amount of compute (88 TFLOP) and storage (3.3 PB) that will be sufficient to satisfy the Swedish node's SRCNet Version 0.3 requirements through to the end of 2027. This deployment will allow Swedish users to successfully work with the first data coming from the partially complete SKA.

LOFAR 2.0 Installation - The upgrade of OSO's LOFAR station to LOFAR 2.0 standard, funded by a 8 Mkr grant from VR for infrastructure upgrades approved in 2021 will finally occur during 2025. The new electronics for this project, as noted in the previous section, has had multiple delays in design and production beyond OSO's control.

Triband VLBI receiver - This proposal requests funding for the construction of a Triband receiver for OSO's 20m telescope. If funding for this is approved the work on ordering components and on construction will begin during the last year of the current OSO contract in 2026 with this project being completed during the first year of the new contract (with the non-labour construction costs for components charged, according to Chalmers accounting rules, to the VR grant in 2027, i.e. once the new receiver is operational).

Prototype new ALMA Band 7 receiver on APEX - The existing Band 7 receiver at APEX will be shipped to Chalmers by late 2025 and during 2026 upgraded by the OSO GARD group with new wider band components to satisfy the requirements of the ALMA Wide Band Sensitivity Upgrade (WSU). This is in preparation to deliver this upgraded receiver to APEX by latest end of 2027 to enhance APEX capabilities for VLBI and demonstrate on-sky GARD's new prototype Band 7 WSU compatible ALMA receiver.

Key numbers for the current grant period

See following page for attachment

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

Kategorier av nyckeltal

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

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

Förklaringar till tabell 2, 3 och 4:

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

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

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

Grämarkerade fält är inte aktuella för OSO.

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

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

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

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

Infrastrukturens namn: OSO
Diarienummer: 2017-00648
Respondent (namn): John Conway
Respondent (epost): john.conway@chalmers.se
Respondent (telefon): 031-772 5503
Anser år: 2019

Kategorier av nyckeltal

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

1. Anställda vid infrastrukturen	
1.1. Enskilda individer	
Totalt	54
Astro user support / ARChnode (Modul 2)	6
APEX svensk tid (Modul 3)	4
Astronomisk VLBI (Modul 4)	5
LOFAR (Modul 5)	2
Geovetenskap (Modul 6)	13
Utveckling av mm-mottagare (Modul 8)	8
Utveckling av cm-mottagare (Modul 9)	7
Ledning (Modul 1)	4
Övriga tjänster (Modul 10)	5
1.2. FTE	
Totalt	34,0
ALMA / ARChnode (Modul 2)	3,3
APEX svensk tid (Modul 3)	3,1
Astronomisk VLBI (Modul 4)	3,2
LOFAR (Modul 5)	0,8
Geovetenskap (Modul 6)	5,0
Utveckling av mm-mottagare (Modul 8)	6,5
Utveckling av cm-mottagare (Modul 9)	6,2
Ledning (Modul 1)	1,9
Övriga tjänster (Modul 10)	4,0

Förklaringar till tabell 2, 3 och 4:

- ALMA:** Tabell 2: Projekt med en nordisk PI. Cycle 6 (observationer oktober 2018 - september 2019)
Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle 6.
Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal projekt.
- APEX:** Alla projekt på svensk tid. Period P103 och P104 (observationer 2019).
- Astronomisk VLBI:** Alla förslag inlämnade 2019. Alla observationer utförda 2019.
- LOFAR:** Alla projekt i Cycle 11 och 12 (observationer november 2018 - november 2019)

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

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

Gränsmärkat fält är inte aktuella för OSO.

	a. Alla projekt			b. Typ av hemvist för alla PI			c. Typ av akademisk hemvist för PI (endast akademiska hemvister)					
	Totalt	Män	Kvinnor	Akademisk Totalt	Män	Kvinnor	Kommersiell Totalt	Offentlig Totalt	Övriga Totalt	Chalmers	Annat svenskt lärosäte	Internationell
2 Projekt												
2.1 Sökta projekt												
Totalt	250	165	85	250	165	85				59	7	184
ALMA (projekt med nordisk PI)	92	54	38	92	54	38				46	6	40
APEX svensk tid	33	22	11	33	22	11				9	1	23
Astronomisk VLBI	75	55	20	75	55	20				2	0	73
LOFAR	50	34	16	50	34	16				2	0	48
2.2 Genomförda projekt												
Totalt	86	59	27	86	59	27				16	3	67
ALMA (projekt med nordisk PI)	19	12	7	19	12	7				10	2	7
APEX svensk tid	17	11	6	17	11	6				4	1	12
Astronomisk VLBI	22	15	7	22	15	7				1	0	21
LOFAR	28	21	7	28	21	7				1	0	27

3 Användare	d. Alla användare			e. Typ av hemvist för alla användare			f. Typ av akademisk hemvist för användare (endast akad. hemvister)		
	Totalt	Män	Kvinnor	Akademisk Totalt	Män	Kvinnor	Kommersiell Totalt	Offentlig Totalt	Övriga Totalt
3.1 Sökta projekt									
Totalt	861	630	231	861	630	231			
ALMA (nordiska användare, alla projekt)	143	103	40	143	103	40			
APEX svensk tid	116	73	43	116	73	43			
Astronomisk VLBI	421	328	93	421	328	93			
LOFAR	287	203	84	287	203	84			
3.2 Genomförda projekt									
Totalt	495	356	139	495	356	139			
ALMA (nordiska användare, alla projekt)	65	46	19	65	46	19			
APEX svensk tid	87	51	36	87	51	36			
Astronomisk VLBI	149	118	31	149	118	31			
LOFAR	235	171	64	235	171	64			

4 Typ och kvantitet av tillgång	g. Total kvantitet per typ av tillgång till infrastrukturen			h. Kvantitet av tillgång för akademiska projekt		
	Alla användare	Fysisk tillgång till infrastruktur		Totalt	Män	Kvinnor
4.1 Användning under året	Fysisk	Data	Prover			
Totalt	n/a			n/a	n/a	n/a
ALMA (antal projekt med nordisk pl)	19			19	12	7
APEX svensk tid (h)	439			439	231	208
Astronomisk VLBI (h)	1112			1112	1028	84
LOFAR (h)	5161			5161	4580	581
Geodetisk VLBI (h)	1768			1768	n/a	n/a

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

Användare	d. Alla användare		e. Typ av hemvist för alla användare				f. Typ av akademisk hemvist för användare (endast akad. hemvister)					
	Totalt	Män	Kvinnor	Akademisk Totalt	Män	Kvinnor	Kommersiell Totalt	Offentlig Totalt	Övriga Totalt	Chalmers	Annat svenskt lärosäte	Internationell
Sökta projekt												
Totalt	955	711	244	955	711	244				53	34	868
ALMA (nordiska användare, alla projekt)	132	90	40	132	90	40				37	28	67
APEX svensk tid	124	84	40	124	84	40				28	2	94
Astronomisk VLBI	424	336	88	424	336	88				7	6	411
LOFAR	377	276	101	377	276	101				8	2	367
Genomförda projekt												
Totalt	632	474	158	632	474	158				36	14	582
ALMA (nordiska användare, alla projekt)	49	36	13	49	36	13				16	8	25
APEX svensk tid	45	30	15	45	30	15				17	0	28
Astronomisk VLBI	324	248	76	324	248	76				8	5	311
LOFAR	275	208	67	275	208	67				8	1	266

4 Typ och kvantitet av tillgång	g. Total kvantitet per typ av tillgång till infrastrukturen				h. Kvantitet av tillgång för akademiska projekt			
	Alla användare		Prover		Fysisk tillgång till infrastruktur		Kvinnor	
4.1 Användning under året	Fysisk	Data			Totalt	Män		
Totalt	n/a				n/a	n/a		
ALMA (antal projekt med nordisk pl)	6	806 GB			6	5		
APEX svensk tid (h)	79	3388 records			79	29		
Astronomisk VLBI (h)	1291	639 TB/40 TB			1291	990		
LOFAR (h)	3202	6 PB/7 PB			3202	2910		
Geodetisk VLBI (h)	1717				1717	n/a		

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

Infrastrukturens namn: OSO
Diarienummer: 2019-00208 (VR), LM 2021/018157 (Lantmäteriet)
Respondent (namn): John Conway
Respondent (epost): john.conway@chalmers.se
Respondent (telefon): 031-772 5503
Avser år: 2021

Kategorier av nyckelta

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

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

Förklaringar till tabell 2, 3 och

ALMA: Tabell 2: Projekt med en nordisk PI. Cycle 7 (observationer oktober 2019 - september 2021*). Genomförda = projekt med minst ett levererat dat.
*Cycle 7 förlängdes till 2 år i stället för det vanliga 1 år p.g.a. pandemin. DDT-proposaler (DDT = Directors Discretionary Time) är inte medräknade i statistiker

Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle

Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal pro

APEX: Alla projekt på svensk tid. Sökta projekt för perioderna P108 och P1

Astronomisk VLBI: Alla proposaler inskickade 2021. Alla observationer utförda 20:

LOFAR: Alla projekt i Cycle 16 och 17 (observationer november 2020 - november 202

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

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

Grämarkerade fält är inte aktuella för OSO

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

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

g. Total kvantitet per typ av tillgång till				h. Kvantitet av tillgång för akademiska projekt			
infrastrukturen				Fysisk tillgång till infrastrukt			
Alla användare		Prover		Totalt		Kvinnor	
Fysisk		Data		Totalt		Män	
4 Typ och kvantitet av tillgång							
4.1 <i>Användning under åre</i>							
Totalt		n/a		n/a		n/a	
ALMA (antal projekt med nordisk P		14		14		10	
APEX svensk tid (h		387		387		151	
Astronomisk VLB (h		1816		1816		1380	
LOFAR (h)		2899		2899		2726	
Geodetisk VLB (h)		2074		2074		n/a	

5 Output	
5.1 Publikationer	Se bifogad list.
5.2 Patent	n/a

Infrastrukturens namn: OSO
Diarienummer: 2019-00208 (VR), LM 2021/018157 (Lantmäteriet)
Respondent (namn): John Conway
Respondent (epost): john.conway@chalmers.se
Respondent (telefon): 031-772 5503
Avser år: 2022

Kategorier av nyckelta

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

1. Anställda vid infrastrukture	
1.1 Enskilda individer	
Totalt	47
Astro user support / ARNode (Modul	6
APEX svensk tid (Modul 1	3
Astronomisk VLBI (Modul 4	4
LOFAR (Modul 5)	2
Geovetenskap (Modul 6)	11
Utveckling av mn-mottagare (Modul 8)	9
Utveckling av cm-mottagare (Modul 9)	5
Ledning (Modul 1	3
Övriga tjänster (Modul 1C	4
1.2 FTE	
Totalt	29,1
Astro user support / ARNode (Modul	4,2
APEX svensk tid (Modul 1	2,4
Astronomisk VLBI (Modul 4	2,6
LOFAR (Modul 5)	0,8
Geovetenskap (Modul 6)	4,9
Utveckling av mn-mottagare (Modul 8)	6,8
Utveckling av cm-mottagare (Modul 9)	3,3
Ledning (Modul 1	1,7
Övriga tjänster (Modul 1C	2,4

Förklaringar till tabell 2, 3 och

ALMA: Tabell 2: Projekt med en nordisk PI. Cycle 8 and 9 (observationer oktober 2021 - september 2022). Genomförda = projekt med minst ett levererat dat

Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle 8 and

Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal pro

APEX: Alla projekt på svensk tid. Sökta projekt för perioden P1:

Astronomisk VLBI: Alla proposaler inskickade 2022. Alla observationer utförda 20.

LOFAR: Sökta projekt i Cycle 18 (Cycle 19 hade ingen "call for proposals"). Genomförda observationer november 2021 - november 21

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

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

Grämarkerade fält är inte aktuella för OSO

Projekt	a. Alla projekt			b. Typ av hemvist för alla P			c. Typ av akademisk hemvist för PI (endast akademiska henvister			
	Totalt	Män	Kvinnor	Akademisk		Övriga	Chalmers	Annat svenskt lärosäte	Internationel	
				Totalt	Kvinnor					
Sökta projekt										
Totalt	257	175	82		257	175	82	78	8	171
ALMA (projekt med nordisk PI)	123	75	48		123	75	48	61	8	54
APEX svensk tik	22	16	6		22	16	6	10	0	12
Astronomisk VLB	85	68	17		85	68	17	7	0	78
LOFAR	27	16	11		27	16	11	0	0	27
Genomförda projekt										
Totalt	107	80	27		107	80	27	15	1	91
ALMA (projekt med nordisk PI)	15	12	3		15	12	3	5	1	9
APEX svensk tik	23	15	8		23	15	8	9	0	14
Astronomisk VLB	46	35	11		46	35	11	1	0	45
LOFAR	23	18	5		23	18	5	0	0	23

3	Användare	d. Alla användare				e. Typ av hemvist för alla användare				f. Typ av akademisk hemvist för användare (endast akad. hemvister							
		Totalt		Kvinnor		Akademisk Totalt		Män		Kvinnor		Kommersiell Totalt		Offentlig Totalt		Övriga Totalt	
	Sökta projekt	834	604	230		834	604	230									
	Totalt	146	97	49		146	97	49									
	ALMA (nordiska användare, alla projekt)	91	57	34		91	57	34									
	APEX svensk tit	463	355	108		463	355	108									
	Astronomisk VLB	134	95	39		134	95	39									
	LOFAR																
	Genomförda projekt	708	522	186		708	522	186									
	Totalt	73	52	21		73	52	21									
	ALMA (nordiska användare, alla projekt)	112	68	44		112	68	44									
	APEX svensk tit	325	253	72		325	253	72									
	Astronomisk VLB	198	149	49		198	149	49									
	LOFAR																

4	Typ och kvantitet av tillgång	g. Total kvantitet per typ av tillgång till infrastrukturen				h. Kvantitet av tillgång för akademiska projekt					
		Alla användare		Prover		Fysisk tillgång till infrastrukt		Fysisk tillgång till infrastrukt			
		Fysisk	Data			Totalt	Män	Kvinnor	Totalt	Män	Kvinnor
4.1 Användning under åre											
Totalt		n/a				n/a		n/a		n/a	
ALMA (antal projekt med nordisk P		15 3974 Gb				15		15		12	
APEX svensk tid (h		367 9888 records				367		367		255	
Astronomisk VLBI (h		1030 860/29.1 Tb				1030		1030		709	
LOFAR (h)		5878 4.4/1.5 Pb				5878		5878		5508	
Geodetisk VLBI (h)		2280								n/a	

5	Output
5.1	Publikationer
5.2	Patent

Se bifogad list:
n/a

Infrastrukturens namn: OSO
Diarenummer: 2019-00208 (VR), LM 2021/018157 (Lantmäteriet)
Respondent (namn): John Conway
Respondent (epost): john.conway@chalmers.se
Respondent (telefon): 031-772 5503
Avser år: 2023

Kategorier av nyckeltal

- 1. Anställda (ensklida individer eller FTE)
- 2. Projekt (representerade av en PI)
- 3. Användare (ensklida individer)
- 4. Kvantitet av användning
- 5. Output

1. Anställda vid infrastrukturen	
1.1 Enskilda individer	
Totalt	55
Astro user support / ARCnode (Modul 2)	10
APEX svensk tid (Modul 3)	3
Astronomisk VLBI (Modul 4)	4
LOFAR (Modul 5)	2
Geovetenskap (Modul 6)	17
Utveckling av mm-mottagare (Modul 8)	7
Utveckling av cm-mottagare (Modul 9)	6
Ledning (Modul 1)	3
Övriga tjänster (Modul 10)	3
1.2 FTE	
Totalt	32,9
Astro user support / ARCnode (Modul 2)	5,8
APEX svensk tid (Modul 3)	2,3
Astronomisk VLBI (Modul 4)	2,6
LOFAR (Modul 5)	0,8
Geovetenskap (Modul 6)	7,6
Utveckling av mm-mottagare (Modul 8)	5,9
Utveckling av cm-mottagare (Modul 9)	4,5
Ledning (Modul 1)	1,6
Övriga tjänster (Modul 10)	2,0

Förklaringar till tabell 2, 3 och 4:

ALIMA: Tabell 2: Projekt med en nordisk PI. Cycle9 (observationer oktober 2022 - september 2023). Genomförda = projekt med minst ett levererat dataset. Tabell 2, forts: DDT-proposaler (DDT = Directors Discretionary Time) är inte medräknade i statistiken här.
Tabell 3: Nordiska användare på alla projekt (även projekt med icke-nordisk PI). Cycle9.
Tabell 4: OSO har inte tillgång till information om observerade timmar, i stället rapporteras här antal projekt.
Alla projekt på svensk tid. Sökta projekt för perioderna P111.
Alla proposaler inskickade 2023. Alla observationer utförda 2023.
Alla projekt i Cycle 19 och 20 (observationer december 2022 - ongoing).

APEX:

Astronomisk VLBI:

LOFAR:

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

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

Gråmarkerade fält är inte aktuella för OSO.

	a. Alla projekt		b. Typ av hänvisat för alla PI			c. Typ av akademisk hänvisat för PI (endast akademiska hänvisat)		
	Totalt	Män	Kvinnor	Akademisk		Kommersiell	Övriga	
2. Projekt				Totalt	Män	Totalt	Offentlig	Internationell
2.1 Sökta projekt								
Totalt	285			285				
ALMA (projekt med nordisk PI)	105			105			8	215
APEX svensk tid	11			11			8	52
Astronomisk VLBI	100			100			0	0
LOFAR	69			69			5	95
							0	68
2.2 Genomförda projekt								
Totalt	142			142			2	122
ALMA (projekt med nordisk PI)	19			19			2	10
APEX svensk tid	10			10			0	0
Astronomisk VLBI	50			50			0	49
LOFAR	63			63			0	63

Användare	d. Alla användare				e. Typ av hemvist för alla användare				f. Typ av akademisk hemvist för användare (endast akad. hemvister)			
	Totalt	Män	Kvinnor	Akademisk Totalt	Män	Kvinnor	Kommersiell Totalt	Offentlig Totalt	Övriga Totalt	Chalmers	Annat svenskt lärosäte	Internationell
Sökta projekt												
Totalt	972			972						77	23	872
ALMA (nordiska användare, alla projekt)	139			139						43	22	74
APEX svensk tid	47			47						18	1	28
Astronomisk VLBI	449			449						11	0	438
LOFAR	337			337						5	0	332
Genomförda projekt												
Totalt	783			783						57	9	717
ALMA (nordiska användare, alla projekt)	72			72						24	8	40
APEX svensk tid	52			52						23	1	28
Astronomisk VLBI	340			340						7	0	333
LOFAR	319			319						3	0	316

4 Typ och kvantitet av tillgång	g. Total kvantitet per typ av tillgång till infrastrukturen				h. Kvantitet av tillgång för akademiska projekt			
	Alla användare	Prover		Fysisk tillgång till infrastruktur	Totalt	Män	Kvinnor	
4.1 Användning under året								
Totalt	n/a				n/a			
ALMA (antal projekt med nordisk PI)	19	17936 GB			19			
APEX svensk tid (h)	198	2769 records			198			
Astronomisk VLBI (h)	1086	896/10.1 Tb			1086			
LOFAR (h)	5413	6.13/2.0 Pb			5413			
Geodetisk VLBI (h)	3124				3124			

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

Notes of reported KPI numbers

- 1) The individuals and FTE working with Geoscience (Module 6) since 2021 are no longer funded by VR but are still, following the reporting template established before 2018, included in the KPI reports.
- 2) KPI's have only been officially submitted to VR for the years up to 2023. The 2024 KPI will be officially reported by 31st March 2025 – many of the international projects that OSO work with have not yet produced figures for 2024 and so even preliminary numbers for that year are not yet available.

Summary of KPI information

Table 1 below summarizes the number of Swedish users on accepted observing proposals per telescope. For comparison, Sweden currently has 199 professional astronomers who are members of the International Astronomical Union (IAU). Publications are a part of the annual KPI reporting under point 5 but are submitted as an appended publication list. Since these publications lists cannot be included in the foregoing pages Table 2 below presents summary information of the number of publications per telescope per year.

	2018	2019	2020	2021	2022	2023
ALMA	54	33	24	44	42	32
APEX	28	13	17	25	25	24
Astro VLBI	1	5	13	7	3	7
LOFAR	5	5	9	6	2	3
Total	88	56	63	82	72	66

Table 1 – The number of unique Swedish users on accepted proposals divided by telescope.

	2018	2019	2020	2021	2022	2023
ALMA/Swe	42	60	44	65	43	54
ALMA/ARC/Swe	14	16	13	26	16	11
ALMA/Band5/Swe	0	4	4	7	3	4
APEX/Swe	14	12	5	15	17	9
Astro VLBI/Swe	4	15	13	13	24	17
LOFAR/Swe	13	11	9	9	12	8
Total	45	58	44	70	72	49

Table 2 – The number of refereed papers with at least one Swedish coauthor shown per telescope.

In Table 2 above the ALMA/Swe row lists per year all refereed ALMA papers with Swedish authors. The ALMA/ARC/Swe line lists those papers with Swedish authors that received support from ARC node at OSO (the numbers here are less than the line above for all ALMA papers with Swedish authors because many of those papers have a first author from another country and are supported by another ARC node, in contrast all Swedish first author ALMA papers received ARC node support). The ALMA/Band5/Swe line shows papers with at least one Swedish author that used the Band 5 receiver produced by GARD. The last table row giving the total number of OSO supported papers does not include the publications listed in the ALMA/Swe row.

Development of user base

OSO provides crucial telescopes, instrumentation, data and user support to multiple world-leading international radio telescopes such as EVN, LOFAR, ALMA and SKA. The user base of these telescopes is highly international and identifying their overall science impact is complex. In the reported KPI numbers, both international and Swedish users of OSO supported international infrastructures are reported. The Swedish user numbers for different telescopes are summarized in Table 1 above; a notable statistic is that Swedish ALMA users make up more than 25% of the entire Swedish astronomy community. Since also 20% of Swedish astronomers are represented on SKA's Science Working Groups, it is anticipated that the user base of OSO will grow. The pattern of involvement in SKA international Science Working Groups and attendance at national SKA meetings indicates that Sweden entering the SKA is significantly broadening radio astronomy interest in Sweden. By continued investment in the support provided by OSO it will be possible to fully harvest this increased interest to further grow the already considerable impact Swedish astronomy has internationally. Both the involvement in ALMA and SKA has been cited as a strong motivation for applying to Chalmers by postdocs and assistant professor candidates.

Publication statistics provide another measure of science output and a summary table of the KPI reported publications is provided in Table 2 above. A testament to the strong Swedish involvement in ALMA science is that over the reporting period Swedish astronomers (co)authored 12.5% of all ALMA publications. There is potential for Swedish ALMA publications to increase yet more via the ALMA upgrade speeding up observations and reducing ALMA's currently very high oversubscription rate which is a barrier to new observers. The issue of limited supply in face of very high interest in ALMA can also be addressed by Sweden getting guaranteed time in return for delivery of Band 7 receivers.

In addition to the numbers of users and the number of papers produced, an important measure of an infrastructure's success is the scientific impact of the results it enables. As described in the following section this impact is high for OSO with 5 out of the 10 listed papers published in Nature or Nature Astronomy with these and others being highly cited. These high impact papers cover all aspects of OSO's activities including VLBI, ALMA and SKA precursor observations.

Research enabled during the current grant period

The astronomy research enabled by OSO encompasses a broad spectrum of high-priority research areas, as evidenced by the publications in prestigious high-impact journals. The selection of 10 papers below, all with Swedish coauthors, concentrates on the most recent papers published during the reporting period. This list shows only a small part of the total research output enabled by the operations of OSO.

We include after each publication the science questions addressed and a short description of the OSO contribution. The papers are grouped according to module with Papers **A-D** corresponding to Module 2 (Onsala Telescopes). Paper **E** illustrates an astronomy paper directly related to Module 3 (ALMA Receivers). Papers **F - I** are ALMA papers supported by Module 4 (ALMA Regional Centre node). Paper **J** is a paper from a SKA precursor telescope (LOFAR) for which the data processing has been supported by Module 5 (SKA Regional Centre node): this paper also has a direct connection to Module 2 because it uses data from Onsala's LOFAR station.

Module 2

A. "Interpreting LOFAR 21-cm signal upper limits at $z \approx 9.1$ in the context of high- z galaxy and reionization observations", Bradley, G. et al. (2021, **Monthly Notices of the Royal Astronomical Society**, 501,1) **Q2, Q4**
 o Interpretation including significant modelling by Swedish coauthors of earlier LOFAR results (Mertens et al 2020) obtained with significant Swedish participation due to the Swedish LOFAR membership.

B. "First Sagittarius A* Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole in the Center of the Milky Way," Event Horizon Telescope Collaboration (2022, **Astrophysical Journal** 930, 12) **Q1**
 o These VLBI observations utilized the APEX telescope, with observations carried out by OSO staff with support from method experts at OSO including techniques developed at the ARC node.

C. "A repeating fast radio burst source in a globular cluster", Kirsten, F., et al. (2022, **Nature**, Volume 602, p 7898) **Q5**

o Based on VLBI observations using the Onsala 25m telescope.

D. "The Birth of a Relativistic Jet Following the Disruption of a Star by a Cosmological Black Hole", Pasham, D.R., et al. (2023, **Nature Astronomy** 7, 88) **Q1, Q5**

o Based on VLBI observations using the Onsala 25m telescope.

Module 3

E. "Resolved ALMA Observations of Water in the Inner Astronomical Units of the HL Tau Disk", Facchini, S. (2024, **Nature Astronomy** 8, 587) **Q8**

o These observations utilized the distinctive capabilities of ALMA Band 5, specifically designed by OSO's GARD unit to detect water molecules in the planet forming regions of protoplanetary disks surrounding young stars.

Module 4

F. "CON-quest: Searching for the most obscured galaxy nuclei", Falstad, N., et al. (2021, **Astronomy & Astrophysics** 649, 105) **Q1, Q4**

G. "Observational identification of a sample of likely recent common-envelope events", Khouri, T., et al. (2022, **Nature Astronomy** 6, 275) **Q9**

H. "A spectacular galactic scale magnetohydrodynamic powered wind in ESO 320-G030", Gorski et al. (2024, **Astronomy & Astrophysics** 684,11) **Q4, Q6**

I. "One month convection timescale on the surface of a giant evolved star", Vlemmings, W., et al. (2024, **Nature** 633, 323) **Q9**

o All of the above four projects were supported by the ALMA Regional Centre node at OSO.

Module 5

J. "Sub-arcsecond resolution imaging of M51 with the international LOFAR Telescope", Venkattu D. et al. (2023, **Astrophysical Journal** 953, 157) **Q4**

o This paper forms part of a LOFAR based PhD recently successfully defended at Stockholm University. The data processing for this project was performed using SRC node computing resources (Module 5) and also used data from the Onsala LOFAR station (Module 2).

CV

CV - John Conway

Project leader: John Conway
Birthdate: 19630331
Gender: Male
Country: Sweden

Doctoral degree: 1988-12-09
Academic title: Professor
Employer: Chalmers tekniska högskola

All cv sections are disabled for John Conway on this application.

Publications

Publications - Chalmers tekniska högskola

Project leader: John Conway
Birthdate: 19630331
Gender: Male
Country: Sweden

Doctoral degree: 1988-12-09
Academic title: Professor
Employer: Chalmers tekniska högskola

Register

Terms and conditions

Applications where an organisation is the applicant are signed automatically when registering the application by the person responsible for the organisation application at the administrating organisation.

The applicant's signature confirms that

- the information in the application is correct and complies with the Swedish Research Council's instructions
- the budget in the application is approved
- the research or research-supporting activity described can be given room at the administrating organisation during the period and to the extent stated in the application
- the permits and approvals required have been obtained before the research is started, such as permits from the Swedish Medical Products Agency or approval from The Swedish Ethical Review Authority or an ethical committee on animal experiments
- the applicant will comply with all other conditions applicable to the grant.