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Evaluation 2017 - 2022

NWO Institute ASTRON

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Contents

1. Foreword by the committee chair

It is with pleasure that I present to you the review report on ASTRON – The Netherlands Institute for Radio Astronomy. As the Committee Chair, it was a privilege to lead this comprehensive review, which provides a detailed assessment of ASTRON's activities, achievements, and future prospects. I would like to express my sincere gratitude to all the individuals who contributed to this review process, from the scientists, engineers, students, administrative and technical staff at ASTRON to its external advisors and stakeholders. Their invaluable insights and expertise have been instrumental in shaping this report.

ASTRON has been a cornerstone in the field of radio astronomy for decades, and its impact on scientific discovery, technological innovation, and international collaboration is world-leading. Our review involved extensive consultations with ASTRON's leadership, staff, and external stakeholders, as well as a thorough examination of the Institute's facilities, research programs, and strategic goals. This report covers the multifaceted aspects of ASTRON's operations, highlighting the Institute's significant contributions to the advancement of radio astronomy, as well as its pivotal role in international observatories and consortia. It is evident from our findings that ASTRON has consistently demonstrated a commitment to excellence, fostering a culture of scientific curiosity and technical innovation that transcends country boundaries. Notably, ASTRON's leadership in the Low-Frequency Array (LOFAR) project stands as a testament to its commitment to pushing the boundaries of radio astronomy instrumentation.

LOFAR, under ASTRON's stewardship, has evolved into one of the most advanced and versatile radio telescopes in the world. The collaborative efforts within the international LOFAR consortium have led to ground breaking discoveries across a wide range of astrophysical phenomena, from pulsars and cosmic rays to the early universe. ASTRON's leadership in LOFAR has solidified its reputation as a global leader in the field, and LOFAR remains a critical asset for radio astronomers worldwide. Moreover, the forward-looking vision of ASTRON is exemplified by its dedication to the LOFAR 2.0 project. This ambitious endeavour seeks to enhance LOFAR's capabilities and extend its scientific reach, enabling even more profound insights into the universe's mysteries. LOFAR 2.0 represents a bold step forward in radio astronomy, and ASTRON's leadership in driving this initiative underscores its commitment to remaining at the forefront of scientific and technological innovation.

Throughout our review process, we were deeply impressed by the dedication and passion exhibited by ASTRON's team members. Their unwavering commitment to unraveling the mysteries of the universe through cutting-edge research and the development of ground breaking instrumentation is a testament to the Institute's enduring legacy.

While this report highlights ASTRON's remarkable achievements, it also provides constructive feedback and recommendations aimed at strengthening the Institute's position in the global research landscape. As the scientific community continues to evolve, ASTRON must adapt and innovate to remain at the forefront of radio astronomy and related disciplines.

Advocating for a larger share of the Square Kilometre Array (SKA) project, commensurate with the size and impact of the Netherlands radio astronomy community, is of paramount importance. ASTRON and the Dutch radio astronomy community have made significant contributions to the SKA, which are not reflected in the current SKA membership share. With the current low SKA membership share, the Netherlands is at risk of losing its future leadership in radio astronomy. It is imperative that ASTRON and the NWO, together with their stakeholders, advocate vigorously for an increased (5-10%) share in the SKA to maximize the benefits and the return on investment for both ASTRON and the broader Dutch scientific community.

The report also provides recommendations for NWO. While ASTRON is working on a more structured financial approach than in the past, it remains underfunded for its infrastructure needs. Past budget gaps were temporarily filled through once-off sources and use of financial reserves. The committee stresses to NWO the urgency of addressing ASTRON's budget deficit. Over the past five years, NWO-based funds have not kept up with economic conditions. This shortfall will worsen as ASTRON's required commitments to LOFAR development and SKA involvement further strain finances and staff. Therefore, the committee advises increasing NWO funding to safeguard ASTRON's role as a vital astronomical research facility in the future.

ASTRON has a rich history of accomplishments, has high societal relevance, and its future holds tremendous potential. It is our hope that this report serves as a guiding document to help ASTRON further excel in its mission to explore the universe through radio astronomy. We look forward to the continued growth and success of ASTRON.

Prof. Lisa Kewley

2. Procedure

2.1 Scope of the evaluation

This evaluation was carried out as part of the evaluation of the nine research institutes of the Dutch Research Council (NWO). NWO asked evaluation committees of external peers to perform an evaluation of its research institutes over the period 2017-2022. Quality assurance agency Academion acted as independent intermediary to safeguard the quality of assessment, providing secretaries for each of the site visit and helping the institutes and evaluation committees prepare and execute the site visits together with NWO-I, the institute organization of NWO.

The evaluations were carried out according to the Strategy Evaluation Protocol 2021-2027 (SEP), the protocol for research evaluations in the Netherlands, agreed upon by NWO, the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Universities of the Netherlands (UNL). The committees were requested to carry out the evaluations according to a list of questions derived from the main assessment criteria of SEP (see appendix 1). The assessment was to include a backward-looking and a forward-looking component. The committees were asked to judge the performance of the institute based on the list of SEP questions and to offer its written conclusions as well as recommendations based on considerations and arguments. The main assessment criteria are:

- Research Quality;
- Societal Relevance;
- Viability.

During the evaluation of these criteria, the committees were asked to incorporate four specific aspects relating to how the institute organises and actually performs its research, its composition in terms of leadership and personnel, and how the institute is run on a daily basis. These aspects are:

- Open Science;
- PhD Policy and Training;
- Academic Culture;
- Human Resources Policy.

For more information on the SEP questions, see Appendix 1.

2.2 Composition of the committee

The committee for the evaluation of ASTRON was appointed by the Board of NWO, and consisted of the following members:

- Prof. Lisa Kewley, Harvard University, USA;
- Prof. Melanie Johnston-Hollitt, Curtin Institute for Computation, Australia;
- Dr. Sara Issaoun, Harvard University, USA;
- Prof. Anna Watts, University of Amsterdam, Netherlands;
- Prof. Marion Matters-Kammerer Einhoven University of Technology, Netherlands;
- Prof. Paul Ho, East Asian Observatory, USA.

The committee was supported by Dr. Fiona Schouten (Academion), who acted as secretary on behalf of Academion. Dr. Maartje van Kempen was present during the site visit to support the committee on behalf of NWO-I.

2.3 Independence

Before the site visit all members of the committee agreed to the NWO Code of Conduct, by means of which they declared that their assessment would be free of bias and without regard to personal interest, and that they had no personal, professional or managerial involvement with the institute or its research programmes. It was concluded that even though there were some links between ASTRON and individual committee members, which were openly discussed and taken into account, the committee identified no serious conflicts of interest. The NWO-I representative present during the site visit did not take part in the evaluation, but provided the committee with background information and context on the Dutch science landscape and the position of ASTRON upon request.

2.4 Data provided to the committee

The committee received the self-evaluation report from the institute, including all the information required by the SEP.

The committee also received the following documents:

- Strategic Plan 2021-2030 for Astronomy in the Netherlands, Raad voor de Astronomie
- ASTRON Future NWO-RI Opportunities: Outcomes of Community Consultation Process Report, February 2023
- Scientific Advisory Committee reports 2017-2022
- Publication overview ASTRON 2017-2022
- ASTRON Open Source Policy

2.5 Procedures followed by the committee

The committee proceeded according to the SEP 2021-2027. The secretary instructed the committee chair on her role in the evaluation. In its first meeting on 28 August 2023, the committee was briefed by the secretary on research evaluations according to the SEP 2021-2027, and by the NWO-I representative on the Dutch research landscape and position of the NWO institute therein.

Prior to the site visit, all committee members independently formulated a preliminary evaluation based on the written information that was provided before the site visit. During its preparatory meeting on 3 October 2023, the committee discussed the preliminary evaluations and identified questions to be raised during the site visit. It agreed upon procedural matters and aspects of the evaluation. The site visit took place on 3-6 October 2023 (see the schedule in Appendix 2). After the interviews the committee discussed its findings and comments in order to allow the chair to present the preliminary findings and to provide the secretary with argumentation to draft a first version of the evaluation report. The final evaluation is based on both the documentation provided by ASTRON and the information gathered during the interviews with representatives of the institute during the site visit.

The draft report by the committee was presented to ASTRON and NWO-I for factual corrections and comments. In close consultation with the chair and other committee members, the comments received were reviewed to draft the final report. The report was finalized on 21 December 2023.

3. Evaluation of ASTRON 2017-2022

3.1 About ASTRON

ASTRON, the Netherlands Institute for Radio Astronomy, aims to make discoveries in radio astronomy happen. Located in Dwingeloo, ASTRON is responsible for the operations of the 14 dish Westerbork Synthesis Radio Telescope (WSRT) and the Low Frequency Array (LOFAR), which consists of 100.000 small dipoles. ASTRON is also involved in the design, development and construction of the Square Kilometre Array (SKA) which, when built in Australia and South Africa, will be the largest radio telescope in the world.

ASTRON is part of the institutes organization of NWO and the host of several independent entities. One of these is JIVE (Joint Institute for VLBI ERIC), which supports, operates and develops the European Very Long Baseline Interferometry Network (EVN), a network of radio telescopes located primarily in Europe and Asia, with additional antennas in South Africa and Puerto Rico. EVN performs very high angular resolution observations of cosmic radio sources. Another independent entity within ASTRON is the NOVA Optical/IR instrumentation group that falls under the Dutch astronomy research school NOVA. ASTRON acts as administrative body, and staff in this instrumentation group are hired as ASTRON employees, with funds provided by NOVA.

ASTRON also hosts a commercial company (AstroTec) of which it is sole shareholder for valorization of research through spin-offs and joint ventures. It furthermore plays a role in procuring, constructing and delivering international LOFAR stations. Finally, ASTRON hosts the International LOFAR Telescope (ILT), a foundation under Dutch law where the European partners in the European LOFAR network join forces. ILT will be converted from a foundation to an ERIC (European Research Infrastructure Consortium) in 2023.

Following a restructuring in 2018-2020, the institute is currently organized into three groups: Astronomy & Operations (A&O), Innovation & Systems (I&S), and Business Support & Services (BS&S), which each have group heads reporting to the institute's management team and director. Previously, the Astronomy group was separate from Operations, and the main reason behind the restructuring was to close an experience gap between science and operations. The Science Data Centre Operations (SDCO) and Telescope Operations were combined together with the two science groups of ASTRON: the LOFAR and the SKA Science groups. I&S is responsible for the technical research and development programme, and is organized along technical competence groups, covering the full range of areas needed for end-to-end systems development. BS&S includes HR management, communication, finance, ICT and facilities. The current structure allows for centralized software resources and a shared strategic approach.

Until recently, ASTRON deployed the Apertif (APERture Tile In Focus), including the Apertif Radio Transient System (ARTS) on the WSRT: a next generation observing system using focal plane array technology, in order to significantly expand its field of view and its survey speed, enabling new, innovative types of astronomical research. The Apertif system consists of new Phased Array Feeds (PAFs) that were mounted at the front-end of 12 of the WSRT dishes. The first data were released in 2019. However, due to a lack of structural funding and expert personnel, Apertif was decommissioned prematurely per March 2022 (see 'Viability').

3.2 Mission, vision and strategy

ASTRON's mission is to make discoveries in radio astronomy happen. Its ambition is to lead the world in the full spectrum of end-to-end discovery and achievement in radio astronomy, science, and technology

frontiers. In order to make this happen, ASTRON identified the following targets for the period under review, 2017-2022:

1. Developing the national facilities to deliver (i) the completion of the Apertif surveys and (ii) enhanced operational support for LOFAR science programmes.
2. Improving the efficiency and capabilities of operations of LOFAR (including the International LOFAR Telescope operations, ILT): this will include implementing significant upgrades to hardware and software systems. The result will be an instrument with transformational science capability complementary to the SKA1-Low telescope.
3. To continue national leadership of R&D in novel radio astronomy technologies for the benefit of the national community, servicing LOFAR, ILT and WRST and potentially developing new instrumentation for international customers.
4. Leading and managing the Netherlands' participation in the SKA. This will be achieved via completion of our commitments to the SKA1 pre-construction phase, as well as positioning ASTRON as an expert provider of services, instrumentation, R&D etc. during construction and into the operational phases.
5. Realizing new data management systems to allow the Dutch and wider astronomical communities to exploit LOFAR, WSRT and other data, and to then evolve these systems to meet the SKA-scale demand to serve the national community and integrate with wider EU efforts in sophisticated e-research systems.

For the upcoming period, ASTRON aims to deepen the impact of its strategy by lowering the barriers of access to radio astronomy data, and returning value to all circles of its community and environment through societal, sustainable science. The new mission and vision retain the tested foundations of inspirational science achievement, innovation in technology, and add the new pillars of inclusive workplace culture and equity, and a path-defining commitment to sustainability.

Both the realization of the previous targets and the future strategy and targets will be discussed in various places in this report. The committee notices a shift from a strategy focused mainly on science and technical aspects to one that takes a broader focus and includes some of the major challenges that ASTRON faces regarding staffing, culture and openness (these will be discussed under Viability). The committee applauds the fact that the new strategy is thereby brought in line with the NWO strategic aim of a healthy research culture where open science, recognition and rewards, sustainability, diversity and inclusion, and scientific integrity are core elements.

3.3 Research Quality

Over the past period, ASTRON research has been successful in working towards its mission to make discoveries in radio astronomy happen. In spite of a small decrease in the Covid 19-period, ASTRON scientists have produced between 150-250 peer reviewed publications, many of which have had a high impact in the field of astronomy. According to a study executed by external organization CWTS, the ASTRON staff publications achieved a 43% higher impact than average in the field. This ties in well with ASTRON's aim of being a leader in the field of astronomy with world-wide impact. ASTRON astronomers have also been successful in obtaining personal grants: 2 ERC Starting grants, 2 ERC Advanced grants, 2 Veni personal grants, 1 Vidi and 2 Vici grants. ASTRON also participates in larger projects (e.g., Horizon Europe, National Science Agenda/NWA, FP7). Individual ASTRON scientists have been granted several awards and frequently participate in international networks, conferences, workshops and collaborations.

Aside from publication quantity, impact, and grant success, ASTRON produced research and publications that clearly contributed to scientific development and that fostered new insights. Among ASTRON's contributions is the detection through LOFAR of low-frequency radio waves of aurorae on a red dwarf, which resulted in a publication in Nature Astronomy, 2020. This discovery is the first step towards using radio observations to discover habitable exoplanets and studying the plasma environment they experience. Another contribution has been an enquiry through EVN into the origins of fast radio bursts (Nature 2022), which revealed that a relatively nearby fast radio burst source lives in a surprising environment: a globular cluster that is part of the M81 galactic system. According to the committee, these and other examples (e.g. capturing the signal of the reionization of hydrogen gas caused by the first stars through LOFAR data, investigating the life cycle of supermassive black holes emitting radio waves though combining LOFAR and Apertif, etc.) demonstrate that both ASTRON scientists and the infrastructure of ASTRON made up by LOFAR, WSRT, and EVN, actively contribute to breakthrough insights and technology in astronomy.

In addition, ASTRON contributes to the development of astronomy research through the operation and maintenance of radio telescope facilities for the national and international communities. It receives various grants (NWO-M, NWO-RI, Roadmap Large Research Infrastructures) for playing this role. Its WSRT, whose innovative Apertif technology was discontinued in 2022, yielded scientific impact nonetheless. Over the past period, its international user community spanned 30 countries and over 400 unique scientists, with a promise of more to come when the data is fully reduced.

At present, LOFAR is the flagship driver for ASTRON science. It is currently the largest and highest-resolution radio telescope operating at the lowest frequencies that can be observed from Earth. Unlike single-dish telescopes, LOFAR is a multipurpose sensor network, with an innovative computer and network infrastructure that can handle extremely large data volumes. While LOFAR started as a national project in the Netherlands, it soon expanded to a pan-European effort, which is still growing thanks to planned new stations in Italy and Bulgaria. The span of its stations gives it unprecedented space-telescope-like resolution at metre wavelengths. In the current era, LOFAR has led or complemented science also performed by other low-frequency arrays, such as the Murchison Widefield Array (MWA), Long Wavelength Array (LWA), and the upgraded Giant Metrewave Radio Telescope (uGMRT). In almost all cases, LOFAR outperforms these other instruments in sensitivity or resolution at the corresponding frequencies. In the upcoming SKA era, LOFAR will be updated and will remain scientifically productive and relevant, since it will access lower frequencies than available with SKA-Low and higher resolution at overlapping frequencies.

LOFAR demand from the international astronomy community is consistently high, with factors of two and more oversubscription for all research proposal cycles in the reporting period. LOFAR's community spans the entire world, and expanded by over a factor of 3 in the reporting period from 610 users in 2017 to 2000 in 2022. Between 2017 and 2022, there was a factor of 7 increase in national and international collaborations on LOFAR. The committee concludes that LOFAR has been a crucial facility in developing radio astronomy over the past period, and that it will remain of high importance in future.

ASTRON also contributes to the development of technology and innovations in astronomy. The Innovation and Systems (I&S) department is responsible for all technological innovation within ASTRON. The department has recently defined and executed an ASTRON technology roadmap enabling a clear selection process for prototyping and research, and successfully crafted and implemented a corresponding instrument roadmap that ensures projects are prioritized to reinforce ASTRON's strategic focus and mission. Research highlights in the reporting period have included development of a Tensor Core GPU Correlator – a correlator GPU library that explores novel technologies for correlating signals five to ten times faster and more energy efficiently than existing GPU designs. In software research, algorithmic improvements have

been implemented throughout the full data acquisition and reduction pipeline, including efficiency increases in baseline-dependent averaging, the development of the LOFAR Rapthor data reduction pipeline as well as brand new novel algorithms for gridding (image domain gridding) and W-projection. A milestone achievement of ASTRON's I&S group has been the successful implementation of TMSS, the newly developed Telescope Manager Specification System, used to specify and (dynamically) schedule LOFAR observations, improving the efficiency of the instrument and its operations by adding new functionalities and a higher level of automation. In addition, a custom and novel liquid cooling design was made in-house which dissipates the considerable amount of heat that the electronic components on the board generate. The committee applauds this type of innovation, which is important not only for radio astronomy itself, but also for related fields of technology and engineering.

Finally, during the review period, ASTRON contributed to the development of the SKA Observatory (see also under Viability). The Netherlands was one of the seven countries that signed the SKA Observatory convention in Rome on 12 March 2019, and was first to ratify in August of that year. After its construction started in 2021, a consortium consisting of ASTRON and three software companies was granted a contract to deliver the calibration and imaging software, building on the experience of LOFAR. A second contract was awarded in March 2022 to lead integration and delivery of the SKA-Low correlator and beamformer. Two further contracts are expected to be signed in 2023 and 2024.

The committee concludes based on this evidence that ASTRON is a world-leading institute in the field of astronomy, and produces excellent research both on astronomy and in technology and innovations. LOFAR is undoubtedly advancing knowledge of low-frequency radio astronomy, particularly in our understanding of diffuse and low-surface brightness, steep spectral index sources, where it is now leading the way in uncovering new phenomena. The ASTRON portfolio is very impressive given the size of the institute (51 FTE research staff, 164 FTE total staff). The implementation of improved data and analysis support has been a primary key to that success. The institute plays an important role in international as well as national projects and initiatives, fulfilling a central role in the Dutch astronomy landscape. The committee applauds ASTRON's prominence and its scientific contributions.

3.4 Societal Relevance

ASTRON science is highly curiosity driven, but this does not exclude it from often having clear societal relevance. A prime example of such relevance is its contribution to the development of a European space weather portal. This portal is currently under development as part of the Space Situational Awareness program led by ESA. Typical end users include satellite operators, radio communication and Global Navigation Satellite System (GNSS) users, military, aircraft operators, and electric power operators. With LOFAR, ASTRON has an instrument capable of providing high quality and unique data that can be used for both data products within space weather services, and for improving space weather modelling and forecasting. One of the LOFAR stations is now dedicated to solar and Space Weather physics.

In addition, ASTRON contributes to technology development that is relevant in to a variety of international, national, and regional stakeholders. For instance, ASTRON is working on DISTURB, a warning system for eruptions on the Sun. Both the Dutch Ministry of Defence and the Royal Netherlands Meteorological Institute (KNMI) want to be able to warn military and civilian users of antenna systems for these outbursts, that affect high frequency radio communication and GPS navigation, and that can also disrupt electric power grids or can corrode oil and gas pipelines. ASTRON also developed (with AstroTec Holding) RF-over-Fiber modules for Ingram Networks in the UK. These modules form part of communication links developed for the UK rail network.

ASTRON collaborates with local companies and is a member of the Innovatiecluster Drachten, where local high-tech companies collaborate on technical innovations. Currently, the institute works with local stakeholders on the production of new hardware for its extension of LOFAR with new stations, and for the upgrading of LOFAR (LOFAR2.0). In addition, the development of SKA comes with an expected fair work return for Dutch industry through production orders (€ 9.64 million). In order to gain these contracts, ASTRON invested in a multi-year intensive preparatory phase with Dutch industrial partners.

Over the past period, ASTRON invested in the visibility and accessibility of its state-of-the-art lab infrastructure, aided by a subsidy from SNN (Samenwerkingsverband Noord-Nederland), with the aim of making its facilities and instruments available to other parties and playing a role in training and educating technical experts. ASTRON's Wireless Data Lab (WDL) now offers small and medium-sized enterprises support on developing new products and dealing with technical challenges on wireless data transfer and RFI-disturbance. In the WDL, ASTRON offers expertise, technologies and (test) facilities. The investment has started to pay off, in spite of the pandemic: compared to the previous assessment period, the use of ASTRON's lab facilities by outside partners increased from 5 to 19. ASTRON also offers a radio frequency technology training for engineers, and reached 99 experts from 47 different local and national enterprises during the review period. A one-day course 'Wireless communication' and an English course were recently added to the training portfolio.

ASTRON shares its telescopes with societal partners. WSRT and LOFAR have been used to support the EU's Global Navigation Satellite System through performance measurements for the European Galileo and EGNOS system. This resulted in a series of development and demonstration projects together with industry to ensure the integrity of the Galileo system for critical Safety of Life services, and paved the way towards a role for the WSRT in the recently established Galileo Reference Centre in Noordwijk. Next to this, the WSRT dishes are used for detection in the context of Space Situational Awareness, in collaboration with NATO, for bi-static detections of geo-stationary satellites using the radar of MIT, and in collaboration with TNO and S[&]T to detect and track satellites in low Earth Orbit (LEO) through reflections of GNSS signals.

There is significant public interest in ASTRON science, and its scientists and research are regularly featured in local, national and international news media. They are supported by the ASTRON Communications Team, who serve as liaisons between scientists and news media and who draw attention to ASTRON research with well-viewed and impactful press releases and other communications. Among the highlights over the review period were the research on exoplanet environments (including an explanatory video), and supermassive black holes. ASTRON's most significant scientific discoveries have thus generated media attention worldwide.

The Communications Team at ASTRON invested also in community outreach, educational opportunities and development, particularly in and after the covid pandemic. The most notable achievement for the local community includes the opening and operation of two Open Science Hubs. The Open Science Hub Dwingeloo, called 'De Melkweg', focuses on primary school children and explains what radio astronomy is. The Open Science Hub Exloo, to be opened in 2023, called 'De Oerknal', offers a serious game in which high school students take on the role of an astronomer to solve a scientific question.

The institute opens its doors to the local community of all ages through annually hosting Open Days, seeing hundreds of visitors come to the facility; and Girls Day, introducing girls aged 10 to 15 to astronomy and technology career futures. Another popular initiative is the Milky Way Path (Melkwegpad) at Westerbork. The solar system, the universe and the largest radio telescopes in Europe are central to this walking route, which

runs between Memorial Center Kamp Westerbork and the foot of the WSRT. ASTRON also continues to draw steady visitor numbers to the Dwingeloo telescope next to its main building, thanks to the supporting operation of the CAMRAS Foundation, who run regular summer tours and offer secondary school students the opportunity to do a secondary school research project in which they get to work with measurements from the Dwingeloo telescope.

ASTRON stimulates and facilitates the connection between science and art, for example through the Shared Sky exhibition in 2021 and the art route Into Nature in 2023. Educational outreach remains a strong priority for ASTRON, with scientific and management staff offering lessons at schools and lectures in a range of regional and national forums. During covid, the institute expanded its online and social media presence. It currently offers educational videos on its YouTube channel and has various educational texts on its website, such as a presentation package for primary school students. This content will be expanded in 2023 and will be offered in Dutch on the Open Science Hubs Drenthe website.

According to the committee, it is clear that ASTRON research and technology development are societally relevant. The committee appreciates the fact that ASTRON science and technology are known to a wide public, and that they have a clear positive impact on local and national stakeholders, who work with ASTRON for mutual benefit and development. ASTRON is firmly rooted in the local community, and is looking to expand strategic collaborations in technology development by looking at other domains, such as telecom and defence. In view of the Covid pandemic that took place during the review period, the committee applauds the fact that ASTRON has been able to develop outreach and increase its visibility and accessibility both to scientists and the general public.

The committee finds that ASTRON could further improve its societal impact by employing its WSRT facility (now that Apertif has been terminated) as a training instrument. This could draw in students from the universities joined in NOVA (the universities of Leiden, Groningen, Nijmegen, and Amsterdam), but it is also attractive for engineering students from the technical universities. This would allow ASTRON to draw in the wider national university community outside its traditional partner academic institutions.

ASTRON could consider the development of a visitor's centre where ASTRON could permanently receive interested scientists and the general public. The committee understood that such an initiative may be limited by available funding, and must be carefully attuned with local parties and interests, due to the close proximity of the historical site of Kamp Westerbork as a Holocaust memorial. The committee recommends strengthening the existing connections and relationships with ASTRON's neighbours and local stakeholders and developing collaborations for outreach activities.

Open Science
ASTRON is conducting open science. ASTRON is actively building its linkages with the wider community consisting both of scientists and the general public. ASTRON is involved with a variety of stakeholders both in and outside science, and has been opening up its facilities and research, and collaborating in partnerships and projects with societal partners. In its future strategy, this engagement will be further strengthened by a 'community-driven astronomy' approach.

ASTRON has an open attitude towards open access practices and policies. Open access and availability of research data have long been a standard in astronomy, and ASTRON is no exception to this. Publications from both the A&O and the I&S groups are available through arXiv (green open access), and increasingly also under more favourable conditions, e.g. Astronomy & Astrophysics' Subscribe-to-Open model or gold open access. LOFAR (raw) data can be retrieved by any scientists or member of the public after the 12 month

proprietary period and support is available for users that encounter difficulties while staging the large data sets. ASTRON is also using and actively developing systems for publishing all or most of its data products through International Virtual Observatory Alliance (IVOA) standard interfaces. ASTRON hosts its own Virtual Observatory server, which contains the major LOFAR and Apertif data releases. 99% of LOFAR publications are open access. The vast majority of software products developed at ASTRON is available through https://git.astron.nl and is in line with ASTRON's Open Source Policy. Both for science and technology papers, best practices on replication packages are developed and are currently implemented within ASTRON.

Recently, ASTRON established a Science Data Centre which develops, distributes and operates a range of software and services that provide data archiving, processing, discovery and analysis. It has an operational unit, SDC Operations (SDCO, 8 FTE), and a development programme (SDCP, 16 FTE). SDCO is the first contact point for internal and external users of ASTRON's facilities, providing support in all phases from proposal preparation to data retrieval. The SDC maintains and develops the LOFAR (LTA) and Apertif (ALTA) archives. In addition, the SDC is well underway with the LOFAR Data Valorisation project, which aims at giving value to the 60PB of data in the archive by generating advanced data products from the existing LOFAR data sets. ASTRON is now building on those components to develop an in-house standardised and supported imaging capability.

The SDC team has also been active in planning for the SKA Regional Centre Network — the internationally distributed network of data centres that will ingest, archive, and support astronomers in analysing the ~1 Exabyte per year of science-ready data products that the SKA Observatory will generate starting later this decade. ASTRON successfully led the Horizon 2020 AENEAS project, which explored technologies and solutions for the SKA Regional Centre Network. During 2021, the SKA Regional Centre Steering Committee constituted a series of working groups to define the requirements for the SRC Network. Through these groups, SDC staff played a major role in shaping the SRC Network as it is now envisioned. For the Science Data Handling and Processing of the SKA-Low telescope, ASTRON is leading a consortium of several companies developing calibration and imaging software.

The committee appreciates ASTRON's commitment to open science practices and recognizes its growth and improvement in this area. The SDC structure helps in coordinating efforts in this regard, which were previously taking shape in a more fragmented and unconnected way in various parts of the organization. Particularly ASTRON's efforts in shaping the SRC network and preparing for the data and storage issues of the SKA era are seen by the committee as necessary and ground-breaking.

The committee agrees that the astronomical community led the world for decades in discoverability; access to data and in 'green' publishing via pre-prints has been the norm for many years. ASTRON has followed international community standards for astronomy. It is only recently that Open Access, FAIR data and software principles have been further refined by the international research community. These newer community trends are currently being adopted by ASTRON. The committee considers this commendable. The committee appreciates the fact that fundamental astronomical software projects are fully documented and made accessible through ASTRON's git repo. However, this is not yet a uniform practice at the level of all institute staff. The committee recommends striving for making all software produced at ASTRON, not just that used to run the observatories, be both FAIR and open. Policy and infrastructure adopted recently appear to be on exactly that track, which is commendable.

3.5 Viability

Future aims
For the period 2023-2027, ASTRON looks to deepen the impact of its mission with strategies that:

- make discoveries in radio astronomy happen for the broadest possible community by lowering the barriers of access to radio astronomy data, and
- return greatest value to all circles of our community and environment through societal, sustainable science.

ASTRON defines the following five-year strategic targets:

1. *LOFAR2.0 success*
   Maintain and extend the international leadership role of LOFAR in low-frequency astronomy through completion of LOFAR2.0 and maximising scientific access to its data for the largest possible astronomy community in the Netherlands and beyond.
2. *Leverage existing infrastructure for next generation science*
   Leverage the existing ASTRON infrastructure and technology capacity to the maximum possible with next-generation developments in strategic and scientifically vital frequency and experimental capacity, ensuring ASTRON provides a viable, complementary and competitive international Observatory well into the next decade.
3. *Securing a strong position in the SKA Observatory*
   Grow the community through science with SKA pathfinders & precursors, including LOFAR, and get strong support to increase our SKA share in order to match the size and strength of the Dutch (radio) astronomy community.
4. *SDC – big data solutions and FAIR access to radio astronomy*
   Develop the Science Data Centre to its fullest extent, with focused resourcing on efficiency gains in near-real-time processing, with output focused on all-access, FAIR, science-ready data products, to ensure the greatest scientific impact for our community, and prioritise the regional centre development for SKA.
5. *Inclusion*
   Advance ASTRON to a role as a national and international leader in equity in STEM, and a role model for successful development of an inclusive, socially-safe workplace culture and equitable opportunity and career development, through equity targets, enhanced recruitment and retention practices, and systemic leadership and management professionalisation. Demonstrate inclusion in outwards roles through greater scientific and technical collaboration and local community support.
6. *Sustainability*
   Prioritise efficiency gains, technology and algorithmic development to reduce the ASTRON carbon-footprint, and use these improvements to reach energy-reduction targets, in combination with scientific capacity. Lead sustainable technology development as a focus hub for Dutch research infrastructures and industry on big data commitment to technology and algorithmic leadership in green computing. Make sustainability an equal weighted factor in ASTRON choices, including in workforce development and career opportunity.

The committee supports the mission and targets named for the upcoming years, which tie in with developments in science worldwide and which reflect policies on open science, academic culture, talent management, recognition and rewards highlighted in the NWO strategy. The aims reflect both ASTRON's high scientific ambitions and a broader conception of ASTRON as a responsible business partner, employer,

and innovator. The committee finds that the strategy and aims, which lean on the four foundational pillars of inspiration, innovation, inclusion, and sustainability, are clearly conceived for the long term and contribute to making ASTRON future-proof. It understands that at this point, translating these pillars into concrete points of action is still work in progress, and that ASTRON management is working hard at realizing this. The committee considers ASTRON's effort on achieving environmental sustainability commendable. This is a necessary development, as the energy resources for computing will only increase in the coming years.

Financial viability
Over the past years, ASTRON's annual overview of funding and expenditure demonstrated consistent deficits of € 1-2 million (see appendix 3). Over this period, ASTRON leadership was aware that income was not sufficient to meet the salary and operational costs of the institute, and took several internal steps to mitigate the issue. A number of one-off funds were used to deal with these issues, including the roughly €7 million of ASTRON financial reserves available. An important decision, which had strong impact on ASTRON personnel, was the early end and decommissioning of Apertif in order to reduce the operational cost burden on ASTRON resources.

In 2022, upon the arrival of the new Director, a methodical review of the finances was conducted to understand the underlying source of the annual deficits. The analysis clearly showed that the operational infrastructure costs for ASTRON had steadily expanded in line with the increasing number of users and impact, while NWO base funds had not. ASTRON relies on project and other grants for half of its income, and is successful enough in obtaining these. It also acquires technology grants and is involved in networks and consortia to maintain and expand this success. However, there are currently no external grant opportunities available to ASTRON for operational funds including maintenance and necessary development activities. The steady (and scientifically justifiable) growth of the LOFAR operation in particular has not come with a corresponding increase in the base subsidy from NWO. The analysis revealed a far greater diversion of staff time to operations than was allotted. It also showed a subsequent lack of staff availability for their assigned tasks in science and development project acquisition and completion. The analysis showed a significant gap between the staff available (70 FTE in 2023) and the staff resources needed (100 FTE) for telescope operations.

The committee discussed these issues with ASTRON stakeholders and management. It learnt that all those involved agreed that ASTRON had stretched beyond its means over the past periods due to high scientific ambitions. The closing down of Apertif/ARTS was a necessary, but painful decision, which the committee supports. The failure to secure additional funding and the mismatch between staff available and staff needed for the Apertif project that existed since its inception left the ASTRON directorate with no viable alternative. The committee applauds the fact that the current ASTRON leadership has invested in creating a clear picture of the issues at hand and the actual distribution of staff time. It finds that this is the only way forward to securing financial stability for ASTRON. The institute is currently investing in the structural, institute-wide professionalization and streamlining of project acquisition, control and completion, to ensure that future projects will be more adequately resourced, with a focus on appropriate assessment of costs, timelines and personnel requirements. The committee learnt during the site visit that non-permanent contracts are given out frequently, also in operations and technology, which does not help to retain good staff members. ASTRON should investigate what constitutes the best strategy concerning permanent or temporary contracts.

According to the committee, ASTRON is positioning itself for a more controlled and structural approach to ensuring financial stability. However, these efforts cannot solve the fact that ASTRON is structurally underfunded as it does not receive sufficient base funding for its current infrastructure requirements. So far,

ASTRON has dealt with its budget deficiencies by using ad hoc, temporary solutions, such as a € 5 million payment between 2019 and 2021 as part of an agreed compensation from the windmill industry after demonstration of radio interference from constructed windmills with the LOFAR telescope array (not shown in appendix 3). The institute also used its financial reserve. The committee points out that ASTRON's budget deficit is a problem that needs to be dealt with urgently. The growth rate of the NWO-based funds over the last 5 years has been too low in comparison to economic conditions, and this gap will only increase as ASTRON's necessary LOFAR development and SKA involvement will place an ever greater strain on finances and staff. The committee advises an increase of NWO funding to mitigate these risks and to allow the institute to retain its importance and centrality as an astronomical research facility in the future.

SKA participation
ASTRON is and has been one of the drivers in the development of the SKA Observatory, thus contributing to opening up a new era in radio astronomy. In 2018, a plan for Dutch membership was completed based on a € 30 million contribution from the Ministry of Education and a € 9.1 million contribution from ASTRON. As part of the membership plan, NWO provided € 2.6 million to fund continued membership of the SKA Organisation in 2019 and 2020 as well as € 1.5 million for ASTRON and its partners to bridge the transition period until the SKA Observatory was formally established as an international treaty organisation. ASTRON expects to play a leading role in helping commission the array and extracting the first science results, especially from SKA-Low, considering the expertise in low frequency operations gained with LOFAR. ASTRON's SKA Regional Centre and SKA Observatory Development Program will also cement the institute's long-term engagement with the SKA at a scientific and a technological level.

In the next decade, ASTRON, along with Dutch radio astronomers, will have to compete with well-funded SKA member countries for telescope access, and thus, scientific return. The access granted is based on the share that the Netherlands have in the SKA1 design baseline. At present, this share is around 2%. Based on the scientific capacity and previous intellectual contributions of the Dutch radio astronomy community, which includes co-authorship of the 2000-page SKA science book and leading roles in the SKA Science work groups, a higher share (5-10%) is more reflective of the Dutch impact in the project. ASTRON therefore intends to mobilize the Dutch community to increase this share over the coming years. In order to do so, it has established the NL SKA Community council formed by astronomers across NOVA institutes and science areas.

The committee considers the share of 2% clearly too limited, and not representative of the importance of the Netherlands as a historical frontrunner in radio astronomy. If this percentage is not raised, the role that the Netherlands and ASTRON have played in the creation and development of the SKA will not yield sufficient return on investment. The relatively small share poses a threat to the Dutch radio astronomy community not only because Dutch scientists will have to compete with scientists from other countries that have more access, but also because research and technological talent will look outside the Netherlands for opportunities in better-positioned countries. The committee considers the current small share in SKA a direct threat to ASTRON's viability and the position of the Dutch radio astronomy community at large.

The committee therefore urges the ASTRON management to quickly take the lead in mobilizing the community to increase this share to 6%, which it finds reflects the Dutch contribution more fairly. The Dutch government and its funding bodies should be alerted to the importance of the Netherlands for the international radio astronomy community, and the impact that the smaller stake in SKA will have on its future. Importantly, ASTRON should not be doing this alone. The Dutch universities and NWO should rally behind the institute. The NL SKA Community council founded by ASTRON is a first step in this process, which the committee feels should be accelerated.

ASTRON has a Science Advisory Committee (SAC), which provides strategic advice on scientific priorities and review of the scientific performance of the institute as well as its effectiveness as a scientific provider to the astronomical community. The committee met with SAC members, who represent the universities in NOVA (Leiden, Amsterdam, Groningen and Nijmegen), and discussed the low SKA stake with them. It finds that the SAC has the potential to act as advocates on behalf of ASTRON, the NOVA universities, and the radio astronomy community. In order to play this role, the SAC should be expanded to also include members of all the technical universities, and terms of reference reviewed and modified where necessary to ensure that SAC members will advocate for ASTRON and the broader Dutch radio community. In this way, by presenting a unified front, the Dutch SKA community can be stronger and more visible and vocal in order to achieve a 6% share of SKA.

LOFAR Governance Structure

At present, LOFAR, initiated at ASTRON and having its core 38 stations in the Netherlands, has expanded to 52 stations across 8 European countries and 10 international member countries. In order to enable easier collaboration, the partners led by ASTRON formed the International LOFAR Telescope (ILT), a foundation under Dutch law. This was the most convenient way to give legal personality to the collaboration between the universities and institutes that own and host the LOFAR stations. Like JIVE, which converted from a foundation to an ERIC (European Research Infrastructure Consortium) in 2015, the ILT will also become an ERIC in the course of 2023. ASTRON is both a member of the ILT and future ERIC, and has a Service Level Agreement (SLA) between the ILT and ASTRON in which ASTRON agrees to operate and maintain the LOFAR telescope for the ILT. The ERIC will enable ease of cross-Europe collaboration and access to European funding opportunities.

The committee learnt that this change in structure is expected to have some benefits, which include allowing for government involvement by the member countries and the possibility that the LOFAR ERIC should be recognized as entity that can apply to national funds. However, in the envisaged structure, decision making is done through majority vote by the countries represented in the council. The statutes state that the hosting director cannot act as voting member of the ERIC's council. Since the ASTRON director is hosting director, this means that there is no ASTRON vote on the council. The committee considers this setup to be risky. This setup does not take into account the significant financial and personnel investments in LOFAR made by ASTRON / NWO. The setup also positions ASTRON (as the host and primary funding body) and the ERIC council (as the decision-making body) against each other in the case of differences of opinion. The committee strongly advocates that ASTRON as the host of LOFAR should have a commensurate share in decision-making and urges this structure be revised as soon as possible. At minimum, the ASTRON Director must have an ex-officio voting seat on the ERIC council as host institution.

HR policy, academic culture, and PhD policy and training

Over the past period, ASTRON has worked hard to improve and develop its processes and policies, restructuring its groups and departments to enable more institute-wide strategies and approaches. In line with current debates on recognition and rewards, ASTRON places enhanced focus on ensuring that less academic, but critical contributions to research are acknowledged and rewarded. ASTRON currently requires all scientific publications using ASTRON facilities acknowledge the technical and operational contributors, with plans to extend this requirement to ASTRON software developers. The institute is also adapting the R&O process (annual individual performance evaluations) to ensure that evaluations are more balanced and fair. A 'Strategic Personnel Planning' is performed (and is repeated on a yearly basis), where the group leaders are challenged to think about the size, expertise, competences and diversity of their group in five-year future views. ASTRON is currently introducing leadership trainings and workforce development.

The current management is planning to continue and enhance these efforts, as can be seen in the new strategy, which the committee appreciates. ASTRON's new organizational structure is geared towards cooperation, research integrity, recognition, and professionalization, bringing operations and science closer together and sharing facilities across the institute. The new director organized listening sessions across the organization, introducing a consultative leadership style that is appreciated by ASTRON personnel. The committee applauds these initiatives, which are in line with ASTRON and NWO strategy.

In addition, ASTRON's new leadership and five-year strategy aim to improve diversity within the ASTRON workforce. The current gender representation averages 26% women across the organisation. The highest proportion of women in the institute is found in the administrative and business departments at an average of 42%, while the A&O and I&S departments show far lower female representation, with averages of 22% and 11% respectively. Additionally, the demographic of the institute is mainly Dutch, with 73% of the staff from the Netherlands, 18% from other European countries and 6% from international locations beyond Europe (2022). The development of social safety practices and a robust code of conduct implementation policy and reporting structure is currently prioritized to create a safer, more inclusive workplace culture.

Post-COVID, a hybrid working scheme was trialled. The institute aims to gather all employees at ASTRON on Wednesdays. Apart from this, they are free to work from home when possible and depending on the habits and expectations in their specific unit or research group. As a result, attendance is low, which has been identified as a problem by ASTRON management and is considered a major problem by the committee. A vibrant academic culture, where dialogue and exchange are made possible and where the various blood groups of scientific, technical, operational, and support staff meet, requires (physical) presence of the ASTRON workforce.

The committee learnt from its conversations during the site visit that many positive changes have been implemented already, and that the current leadership is a catalyst for such processes. ASTRON is putting a significant effort into boosting its culture, social climate, diversity and safety, for instance by promoting equitable hiring practices, revising processes, attempting to bring people into the office regularly, and introducing sensitivity trainings. At the same time, the committee noticed that academic culture, HR policies and practice, and diversity and inclusion require even more attention henceforth.

Regarding diversity, inclusion, and social safety, the committee learnt during the site visit that not all staff members are comfortable with, or in support of, the changes made in promoting diversity and awareness. A section of employees is averse to changes, and is vocal about this, which can create an unsafe atmosphere, which is against the mission and future success of the organisation. The committee considers that significant work needs to be done to improve social safety for the benefit of the ASTRON community as a whole. The committee strongly recommends strengthening HR and conduct policies in order to abolish disruptive behaviour and to consistently enforce strong HR practices and procedures broadly. The committee recommends that leadership accelerate its efforts to close diversity gaps and to build an inclusive environment to ensure the psychological safety and retention of members of underrepresented minority groups within ASTRON.

Also in this context, the committee recommends expanding the works council to include members with more diverse backgrounds than is currently the case, and to make sure that all of ASTRON feels represented. The current membership of the works council runs the risk that its recommendations could be seen as biased or opposing the needs of members of underrepresented minority groups. The committee also recommends giving the Equity and Inclusion committee a more structural and future-proof place in the organization.

Regarding the academic community, the committee noticed a clearly inspiring and fertile collaboration among scientific employees, particularly those in middle management. However, this atmosphere is lacking elsewhere in ASTRON. The committee noticed a distance between ASTRON's various groups. The science and operations personnel at the ASTRON main building are far removed from the engineers working on the LOFAR and WSRT sites and have very limited contact with them. In this context, the committee was told by various stakeholders that ASTRON employees do not frequent either the institute or participate in its activities. ASTRON has a liberal culture regarding attendance. This was born out of necessity: employees live removed from the ASTRON main building and experience the commute as a strain. The liberal culture became more dominant during the Covid pandemic. On top of this, the recruitment and retention of expert personnel is a challenge for ASTRON, which makes ASTRON supervisors reluctant to demand too many sacrifices from their staff. Research software engineers and developers are needed to provide the necessary staff for the SDC, whose role will only increase in importance and size when LOFAR 2.0 and SKA yield more scientific data. Finding and retaining talent in a semi-rural location such as Dwingeloo, in the face of competing facilities elsewhere, is no easy task.

The committee learnt during the site visit that the ASTRON postdocs and PhD candidates suffer most from the limited presence of research (and other) staff. ASTRON postdocs tend to be focused on their own work, often work from home, and feel disconnected from the institute. They are usually hired on a project grant and are not offered an onboarding training or mentorship programme. As a result, they are not aware of research done at the institute and are lacking a clear future perspective. PhD candidates are co-supervised by an ASTRON researcher, but they also always have a supervisor at a university (often also ASTRON employee through joint appointment), since ASTRON as a research institute cannot grant a doctorate. As a result, PhD candidates are embedded at one of the NOVA universities, where they are required to fulfil teaching duties. PhD training is left to the PhD candidate's NOVA university, and there is no ASTRON-specific training programme or mentoring structure in place. This leads to PhD candidates feeling primarily affiliated with their NOVA university, even if they are fully ASTRON funded. PhD candidates are expected to visit ASTRON once a week, but this can be less in practice. ASTRON is difficult to reach by public transport, and a shuttle service instated by ASTRON goes only twice a day.

The committee strongly advises bringing people back into the building by requiring all staff to be present more structurally (for instance, at least three working days on a full-time basis, consistent with other major astronomy institutions world-wide). The entire organization should be stimulated to meet and interact. Currently, coffee meetings are organized per group, sometimes in conflict with other events, and PhD students and postdocs are sometimes kept separate from the body of researchers. The committee recommends organizing meetings strategically for the general population as well as encounters where specific groups interact, such as ASTRON and JIVE, or ASTRON and NOVA to avoid conflicts and advertising all events in a consistent manner. In this way, the junior scientists can be included in the community, contributing to its vibrance and learning from and interacting with senior staff members, both engineers and scientists. The connection with the telescope maintenance staff should also be improved, and ASTRON employees should visit the telescope sites more frequently. By implementing new policies, and reinforcing the sense of community and the exchange of ideas, ASTRON can improve its on-site attendance and support of its community members, including postdocs and PhD students.

In addition, by introducing attractive part-time options, family-friendly meeting hours, and other policies supportive of inclusion and belonging, as well as advertising the family friendly local community and schools, ASTRON may become an attractive employer of choice for potential employees with young families.

Finally, the committee recommends implementing a PhD policy and a mentoring plan, as well as an onboarding trajectory for postdocs, actively inviting them to come into the office. In addition, contact with and between PhD candidates and postdocs should be stimulated, for instance through a Slack workspace with dedicated channel, dedicated events, and an up-to-date face board. The shuttle service should be offered for free to junior researchers, its frequency expanded if possible, and it could be complemented with carpool slack channels to facilitate junior staff coming into the office. ASTRON should work at bringing its younger cohorts into the office more frequently, and to avoid the argument that they are fully committed to their university only by emphasizing the significant funding and support being provided by ASTRON.

With a view to ASTRON's future development and positioning, the committee recommends investing in recruiting more postdocs and PhD candidates, since both ASTRON and the young researchers themselves would benefit from a vibrant, sizeable and productive junior community. The summer research internship programme for graduate students as well as advanced non-graduate students could be strengthened and expanded to include engineering students, in order to draw in more young researchers to ASTRON. The committee points out that currently, ASTRON PhD candidates add to the junior communities of the universities rather than to ASTRON. In addition, PhD candidates provide services at their university which include teaching and BSc or MSc thesis supervision. The universities also receive a substantial bonus for each doctorate awarded. ASTRON should therefore look carefully at the balance of benefits in the relationship with the universities as co-supervisors. ASTRON should insist on receiving benefit from the universities in exchange for the substantial funding, training and telescope time provided by ASTRON to PhD candidates.

According to the committee, ASTRON has much to be proud of and to share with its junior staff members, and it should offer them as many opportunities as possible to benefit from, and be inspired by, its unique qualities. ASTRON's outstanding research quality and societal relevance will be retained and enhanced when the institute offers all of its employees equally a welcoming, vibrant, diverse, and open scientific community.

In conclusion, the committee argues that ASTRON and its management are on the right track to ensure that the institute can continue flourishing in future. It finds that the institute has all the right priorities in its current strategy and development and encourages it to continue translating these into concrete aims and policies. The committee concludes that ASTRON deserves support from the wider Dutch radio astronomy community, and from the Dutch scientific community at large, to maintain its scientific excellence and make the necessary changes as described in its strategy. ASTRON should be given the resources and the support to continue playing a role at the forefront of radio astronomy worldwide.

4. Executive Summary

Conclusion

ASTRON is a world-leading institute in the field of astronomy, and produces excellent research both on astronomy and in technology and innovations. At present, its low-frequency radio telescope LOFAR is the flagship driver for ASTRON science. The institute invests in taking radio astronomy forward by contributing to the development of the SKA Observatory which, when built in Australia and South Africa, will be the largest radio telescope in the world. The institute invests in FAIR and open science practices, and is invested in anticipating future data technology challenges in radio astronomy. ASTRON research also has clear societal relevance, both in terms of the research itself and in terms of community impact, training and co-developing international as well as local business partners and stakeholders. ASTRON has been working on streamlining and improving data and analysis support, which has been a key to its success. Its future strategy and aims, which lean on the four foundational pillars of inspiration, innovation, inclusion, and sustainability, are clearly conceived for the long term and contribute to making ASTRON future-proof.

In order for ASTRON to remain a leading institute in the Netherlands and a pillar of radio astronomy science worldwide, certain issues regarding its viability need to be addressed urgently. An investigation by the current management demonstrates that ASTRON is structurally underfunded due to the fact that its operational and infrastructure costs are not covered by its base NWO funding. The institute is also dealing with a shortage of operational staff. These issues will need to be addressed as ASTRON's necessary LOFAR development and SKA involvement will place an ever greater strain on finances and staff. A further threat to ASTRON's scientific position and ambitions is the Netherlands' low share in the SKA Observatory, which is not representative of the scientific capacity and previous intellectual contributions of the Dutch radio astronomy community, and which leads to limited telescope access for Dutch-based researchers. ASTRON and the entire scientific community, including the technical universities, should join efforts in achieving a higher share. Finally, the conversion of LOFAR's government structure towards and ERIC is problematic, since the ASTRON director is not given a seat on the board and this can lead to a divide between ASTRON management and the council.

Internally, ASTRON is going through a series of transformations concerning professionalization of processes and policies, promoting and improving academic culture, and stimulating sustainability, diversity and inclusion. ASTRON leadership is to be applauded for its efforts in this area to date. In order to accelerate this process, ASTRON should strengthen HR and conduct policies in order to abolish disruptive behaviour and to enforce the HR practices and procedures broadly. This includes expanding the works council to include members with more diverse backgrounds than is currently the case. ASTRON should also invest in bringing people back into the building by requiring all staff to be present structurally (for instance, at least three working days on a full-time basis). The entire organization should be stimulated to meet and interact. This includes the telescope maintenance staff, as well as PhD candidates and postdocs.

Finally, the committee recommends a PhD policy and a mentoring plan, as well as an onboarding trajectory for PhDs and postdocs, actively inviting them to come into the office. The shuttle service should be offered for free to junior researchers, and its frequency expanded if possible, and complemented with carpool slack channels to facilitate junior staff coming into the office. ASTRON should work at bringing its younger cohorts into the office more frequently, avoiding the perception that they are fully committed to their university only and allowing them to benefit from ASTRON's excellent research environment.

List of recommendations

1. Increase NWO base funding to solve ASTRON's structural budget deficit and allow the institute to meet current and future infrastructure requirements.
2. Take the lead in mobilizing the Dutch radio astronomy community to increase the SKA share to 6%, which reflects the Dutch contribution to its development more fairly. In order to play this role, ASTRON's Science Advice Committee should be expanded to also include members of all the technical universities. In this way, by presenting a unified front, the Dutch SKA community can be visible and vocal.
3. Expand collaboration with the technical universities on engineering and technology innovations.
4. Revise the International LOFAR Telescope governance structure as soon as possible by allowing ASTRON a seat on the council.
5. Enforce HR practices and procedures broadly in order to improve academic culture and inclusion and to abolish disruptive behaviour. Expand the works council to include members with more diverse backgrounds than is currently the case. Give the Equity and Inclusion committee a more structural and future-proof place in the organization.
6. Bring people back into the building by requiring all staff to be present a fixed number of working days per week (for instance, three days in office on a full-time basis). Stimulate the entire organization to meet and interact. This includes the telescope maintenance staff, as well as PhD candidates and postdocs.
7. Introduce a PhD policy and mentoring plan, and an onboarding trajectory for PhD candidates and postdocs, actively inviting them to come into the office. Facilitate transportation and access to the ASTRON facilities. Invest in recruiting more postdocs and PhD candidates to create a vibrant, sizeable and productive junior community.
8. Further improve societal impact by employing the WSRT facility as a training instrument, also for engineering students from the technical universities, and by constructing a visitor's centre in close communication with local parties and interest groups.
9. Make all software produced at ASTRON, not just that used to run the observatories, both FAIR and open.

Appendix 1: SEP Questions Evaluation NWO institutes

The 3 main criteria:

1. Research quality:

- How does the assessment committee assess the scientific quality of the institute, in light of its own aims and strategy? Central in this assessment are the contributions to the body of scientific knowledge. The assessment committee is asked to reflect on the quality and scientific relevance of the research. Finally, the academic reputation and leadership within the field is assessed. Looking ahead into the future, which recommendations can the committee give to the institute regarding their research quality?
- How does the committee assess the institute's place in the national and/or international research landscape? Is the institute a frontrunner or a follower in its field? Does the committee see untapped opportunities?

2. Societal relevance:

- How does the committee assess the societal relevance in terms of impact, public engagement and uptake of the institute's research in economic, social, cultural, educational or any other terms that may be relevant? The assessment committee is asked to reflect on societal relevance by assessing an institute's accomplishments in light of its own aims and strategy. Looking ahead into the future, which recommendations does the committee have for the institute regarding its societal relevance?

3. Viability:

- How does the committee assess the extent to which the goals for the coming six-year period remain scientifically and societally relevant? It is also asked to assess whether its aims and strategy as well as the foresight of its leadership and its overall management are optimal to attain these goals. Finally, the assessment committee is asked to assess whether the plans and resources are adequate to implement their strategic plan. The assessment committee is also asked to reflect on the viability of the institute in relation to the expected developments in the field and societal developments as well as on the wider institutional context of the institute.
- How does the committee assess the way the institute fulfills their national role and does the committee have any recommendations regarding this?**1**
- How does the committee assess the way the institute contributes to the vision on 'Dutch research in 2030' as is written down in the NWO Strategy 2023-2027 and does the committee have any recommendations?

1 *With respect to the reports from the PCNI, the portfolio committee and (where relevant) the exploration reports.*

In addition, there are 4 important aspects contributing to the success of the institute:

4.1 Open Science

The assessment committee is asked to consider to which extent the institute opens up its work to other researchers and societal stakeholders in the context of its strategy and policy. Furthermore, the committee is

asked to consider whether the institute reuses data where possible; how it stores the research data according to the FAIR principles; how it makes its research data, methods and materials available; and when publications are available through open access. The committee is specifically asked to give the institute and NWO-I recommendations on their Open Access and FAIR data and software policy. The assessment committee is asked to reflect on the current policies, and the practices with regards to the open availability of the publications, research data and methods and assess them in light of NWO's high ambitions (e.g. is the institute a frontrunner in its field with regard to Open Access and FAIR data and software?).

4.2 PhD policy and Training

- The assessment committee is asked to consider the supervision and instruction of PhD candidates. Furthermore, the committee is asked to consider whether the quality assurance system is functioning properly. The committee is asked for recommendations on how to enhance the supervision and education of PhDs (together with the universities), also in light of the three main criteria.

4.3 Academic Culture

- *Openness, (social) safety and diversity & inclusivity:* The assessment committee is asked to consider the openness, (social) safety and diversity & inclusivity of the research environment. The assessment committee is also asked to evaluate the actions and plans for the future of the institute with regards to (social) safety, diversity & inclusivity.
- *Research integrity:* The assessment committee is asked to consider the institutes policy on research integrity as well as the way the institute facilitates the relevant actions and requirements formulated in the Netherlands Code of Conduct for Research Integrity. For both themes: Looking ahead into the future, which recommendations does the committee have for the institute regarding their academic culture, also in light of the three main criteria?

4.4 Human Resources policy

- *Talent Management:* The assessment committee is asked to consider the institute's policies on talent selection and development in relation to its aims and strategy. More specifically, it is asked to evaluate the institute's recruitment policies, opportunities for training and development, coaching and mentoring, as well as career perspectives for researchers and research support staff in difference phases of their career. An important aspect of this is the (inter)national cultural change regarding recognition and rewarding in academia that NWO-I is implementing. What are the institute's plans to further the desired cultural change and which recommendations does the committee have for the institute and NWO-I?

Appendix 2: Programme of the site visit

Tuesday, 3 October 2023

Arrival; dinner; closed panel session

Wednesday, 4 October 2023

09:00 Presentations MT ASTRON (combined session)
10:45 Business Support & Services
11:15 JIVE – incl. tour JIVE basement
12:15 Lunch with Equity & Inclusion Committee + Sustainability Committee
13:00 Works Council
13:30 Tour of Westerbork and LOFAR
18:30 Dinner with ASTRON MT

Thursday, 5 October 2023 – site visit day 2

08:30 Tour ASTRON Dwingeloo (schedule tbd):
10:15 Science & projects ASTRON (combined session)
12:15 Poster session (astronomical/ technical) (A&O + I&S) + lunch
13:00 PhD students (all available)/postdocs
14.30 Astron director
15:15 Interview with regional stakeholders (combined session):
16:15 Interview with industry partners (combined session):
17:00 Drinks with regional stakeholders, business partners and ASTRON MT

Friday, 6 October 2023 – site visit day 3

08:30 Interview with ILT Board chair
09:00 Interview with SKAO DG (online)
09:30 SAC representatives
10:15 Closed session
11:30 Feedback session (ASTRON MT, SAC)
12:00 Lunch with MT-SAC-panel members

Appendix 3: Quantitative data

Quantitative data on the institute's composition and funding, as described in SEP Appendix E, Tables E2, E3 and E4:

Appendix 1: Staff composition - Institute Facts & Figures

	2018	2019	2020	2021	2022
Research staff					
Scientific staff					
Assistant professor /Jr	14	16	13	13	11
Associate professor / medior	13	14	14	14	12
Full professor / Sr	15	15	15	16	17
Postdocs	11	9	9	7	6
PhD students	5	4	3	2	5
Total Research staff	58	58	54	52	51
Technical staff	64	64	62	65	63
Support staff	47	54	50	48	50
Visiting fellows					1
Total Staff	169	176	166	165	164

Table 1: ASTRON staff complement 2018-2022 (in fte). Staff numbers were not tracked in this format prior to 2018 and so the numbers for 2017 are not shown here.

2017 - 2022 Funding and Expenses

Funding	2017 (kC)	%	2018 (kC)	%	2019 (kC)	%	2020 (kC)	%	2021 (kC)	%	2022 (kC)	%
NWO-Base funds	10,897	54%	11,413	56%	11,672	59%	11,929	67%	12,272	60%	12,556	62%
Project and other	9,426	46%	9,010	44%	8,184	41%	5,833	33%	8,064	40%	7,631	38%
Total funding	**20,323**		**20,423**		**19,856**		**17,762**		**20,336**		**20,187**	
Expenditure												
Personnel costs	14,290	70%	15,455	74%	16,424	74%	16,338	78%	17,606	79%	17,043	79%
Infrastructure costs	6,235	30%	5,564	26%	5,743	26%	4,703	22%	4,772	21%	4,399	21%
Total Expenditure	**20,525**		**21,019**		**22,167**		**21,041**		**22,378**		**21,442**	
Balance	**-202**		**-596**		**-2,311**		**-3,279**		**-2,042**		**-1,255**	

Table 1: Overview of funding and expenditure at institutional level, 2017 – 2022

		Enrolment		Success rates					
Starting year		Enrolment	Total	graduated	graduated	graduated	graduated	Not yet	Discontinued
	male	female	(M+F)	in yr 4 or earlier	in yr 5 or earlier	in yr 6 or earlier	in yr 7 or earlier	finished	
2022	5	1	6					100,00%	
2021	1	2	3					100,00%	
2020	4	1	5					100,00%	
2019	3	0	3					100,00%	
2018	4	5	9	22,2%	44,4%			33,3%	
2017	0	3	3		66,7%	33,3%			
Total	17	12	29						

Table 1: PhD program 2017-2022