Evaluation 2011-2016

ASTRON

Netherlands Institute for Radio Astronomy

Dwingeloo, 14 October 2017

NWO Netherlands Organisation for Scientific Research
dialogic innovatie • interactie
Birch

Content

1 Introduction

1.1 Scope and context of this review

This evaluation concerns the research carried out at ASTRON Netherlands Institute for Radio Astronomy since 2011. The evaluation was commissioned and organised by the Netherlands Organisation for Scientific Research (NWO) and supported by Dialogic Innovation & Interaction and Birch Consultants. The external evaluation follows the Standard Evaluation Protocol 2015-2021 (SEP, amended version September 2016). It is the protocol for research assessment in the Netherlands as agreed upon by NWO, the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Association of Universities in the Netherlands (VSNU). The primary aim of the assessment procedure is to reveal and confirm the research quality, relevance to society and viability and to provide recommendations to improve these aspects. In addition, the procedure includes considerations with regard to PhD programmes, the research integrity and diversity of the (scientific) staff.

An international Evaluation Committee was established and asked to produce a reasoned evaluation of the institute and its research programmes, in accordance with the SEP. Prior to the external evaluation, ASTRON submitted a self-assessment document covering the period 2011-2016 including a strategic forward look. This report was approved by the NWO Executive Board on 5 July 2017. The self-assessment report and addendum included a SWOT analysis and a full set of statistics at institute and programme level concerning input (finances, funding and staff) and output (refereed articles, books, PhD theses, conference papers, publications aimed at the general public, and other output) for the six years prior to the evaluation. A number of tables were included about research staff, main categories of research output, funding, and PhD candidates.

The self-assessment report offered a concise picture of the institute and research groups' work, ambitions, output and resources in accordance with the guidelines provided by the SEP. A site visit formed an important part of the evaluation and included interviews with the management of the institute, the heads of units, group leaders, postdocs and operational staff, as well as a tour of the laboratories and facilities.

1.2 The Evaluation Committee

The Evaluation Committee was appointed on 10 October 2017 by NWO Executive Board representative prof. Jaap Schouten. Its members were:

Prof. Steven M. Kahn (Chair)
Prof. Elaine Sadler
Prof. Tracy Clarke
Prof. Ji Wu
Prof. Scott Ransom

A short curriculum vitae of each of the members is included in Annex 1.
The Committee was supported by Dr Maaike Damen from NWO and Daphne den Hollander from Birch Consultants.

Before the site visit all members of the Committee signed 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.

Upon receiving the Code of Conduct, initial committee Member prof. Erik Fledderus informed NWO of a possible conflict of interest. As Director of SURF, he had been collaborating with ASTRON for a while, mainly through service agreements. However, in the future and with ASTRON's ambition regarding a data science centre, this collaboration is expected to be strengthened.

After discussion with prof. Fledderus, Dr Marco de Vos (managing director of ASTRON) and Director of the NWO Institute Organisation (Christa Hooijer), it was decided that prof. Fledderus would withdraw from participation in the Evaluation Panel. As much as everyone believed that he would be able to perform his tasks as a committee member objectively, it would be better for all parties involved to withdraw him from the Committee at this moment, to avoid a possible *appearance* of conflict of interest, which could potentially negatively affect ASTRON.

It was concluded that the rest of the Committee had no conflicts of interest.

1.3 Data supplied to the Committee

On 9 August 2017, 9 weeks prior to the site visit, the Evaluation Committee received the self-assessment report of ASTRON and appendices together with the site visit programme. The documentation supplied to the Committee included all the information required by the SEP, as well as by the additional questions raised by NWO. It also included the Terms of Reference for the evaluation (including all evaluation criteria); Code of Conduct; Valorisation indicators; Roles of the internal and external secretaries; Composition of the Panel and a short document on practical issues.

A week prior to the site visit, the Evaluation Committee received an additional presentation about the Dutch research landscape. In a meeting with prof. Jaap Schouten (member of the NWO Governing Board), on the first day of the site visit, the Committee was officially installed. In this meeting, prof. Schouten presented the Dutch science policy and the NWO organisation, which led to an interactive discussion about the organisation of scientific research in the Netherlands, including the recent transition of NWO, and the governance structure of the NWO research institutes.

A first video preparatory meeting was held with the Chair of the Committee and Maaike Damen (NWO) and Daphne den Hollander (Birch Consultants) on 10 July 2017. Prior to this meeting, the Chair received documentation (such as a draft site visit programme; self-evaluation; SEP Protocol). A second preparatory meeting was held (by video conference) with the entire Committee on 9 September 2017.

During the site visit the Committee received further documentation, such as an updated programme; information about the Top Sectors; the National Science Agenda; and "2025 – vision for science choice for the future" (Dutch government 2014).

1.4 Procedures followed by the Committee

The Committee proceeded in accordance with the SEP 2015-2021. The assessment was based on the ASTRON self-assessment report, the other documentation provided by NWO and the site visit at ASTRON. During the site visit, a large number of interviews were held. The programme of the visit is included in Annex 2.

The Committee met on the afternoon and evening preceding the site visit. They discussed the SEP Protocol; the purpose of the evaluation; division of tasks, and other issues. The Committee agreed on procedural matters and aspects of the assessment as described in the

following paragraphs. Also, the Committee met with prof. Jaap Schouten, member of the NWO Executive Board.

The interviews with the ASTRON Director, Management Team, Governing Board, Scientific Advisory Committee, Heads of Units, Group Leaders, Operational (scientific) staff; PhD students, postdocs, Diversity Committee, Workers Council, external stakeholders and support staff took place during the site visit between 11-13 October. All interviews were conducted by the entire Committee jointly. Also, a joint lab tour and trips to the Westerbork telescopes and to LOFAR were included in the site visit.

After completing the interviews, the Committee discussed the scores and comments on the institute and its research programmes and determined the final assessment.

At the end of the site visit, a meeting was held with ASTRON's Director and General Manager, the chair of the ASTRON Governing Board and Christa Hooijer as representative of the NWO Executive Board, to report on the Committee's main findings.

On 18 December 2017, a draft version of this report was sent to the ASTRON director for factual correction and comments. The report was subsequently submitted to the NWO Executive Board for approval.

1.5 Aspects and assessment scale

The SEP 2015-2021 requires the Evaluation Committee to assess three main aspects of the institute and its research. These are:

1. *Research quality.* The Committee assesses the quality of the institute's research and the contribution that research makes to the body of scientific knowledge. The Committee also assesses the scale of the institute's research results (scientific publications, instruments and infrastructure developed by the institute, and other contributions to science).
2. *Relevance to society.* The Committee assesses the quality, scale and relevance of contributions targeting specific economic, social or cultural target groups, of advisory reports for policy, of contributions to public debates, and so on. The point is to assess contributions in areas that the institute has itself designated as target areas.
3. *Viability.* The Committee assesses the strategy that the institute intends to pursue in the years ahead and the extent to which it is capable of meeting its targets in research and society during this period. It also considers the governance and leadership skills of the institute's management.

These three main evaluation criteria were rated according to a four-category scale, as specified in the SEP. The verdict was given in qualitative form, then a quantitative figure is added. The scale is as follows: 1. World leading/excellent; 2. Very good; 3. Good; 4. Unsatisfactory (see Annex 4). In addition to the topics above NWO formulated three questions for all NWO institutes and two specific questions for ASTRON. These topics were only considered in qualitative terms (not using the four-category scale).

1. *PhD programmes.* The Evaluation Committee considered the supervision and instruction of PhD candidates.
2. *Research integrity.* The Evaluation Committee considered the institute's policy on research integrity and the way in which violations of such integrity are prevented.
3. *Diversity*. The Evaluation Committee considered the diversity of the institute. It is precisely the presence of mutual differences that can act as a powerful incentive for creativity and talent development in a diverse institute.

Questions formulated for ASTRON:

- Is ASTRON taking the right steps to prepare for the future in relation to the global SKA project?
- Acknowledgement of the role of support: ASTRON is responsible for two major research infrastructures (WSRT and LOFAR) that are being used by scientists from all over the world to do research and publish in high ranking papers. ASTRON considers the role of its operational staff and support scientists to be essential for these results, but this cannot be made directly visible in publication rankings. Does ASTRON take sufficient action to make this contribution to scientific output visible and acknowledged?

2 Institutional framework of ASTRON

2.1 Mission

ASTRON, the Netherlands Institute for Radio Astronomy, has for many years served as the focal point for the development and operation of forefront radio astronomy facilities and their associated instrumentation within the Netherlands. ASTRON was one of the first such institutes established in the world for this field, and has remained a premier player in the world effort in radio astronomy ever since. The institute has as its mission statement "Making Discoveries in Radio Astronomy Happen". This mission clearly aims at the pursuit of fundamental science, but also points to the essential value of advanced observing facilities coupled with a strong technological R&D programme.

ASTRON has adopted a threefold strategy to accomplish that mission, which includes: (1) Supporting a fundamental science programme in observational radio astronomy carried out by resident permanent staff, postdocs, and PhD students; (2) Building and operating world-class radio observatories; and (3) Pursuing an extensive research and development programme aimed at innovating and prototyping new technologies for the field. Through this suite of activities, ASTRON has established strong partnerships with industry, both within and outside the Netherlands, as well as with comparable scientific institutes in other countries. In many cases, the technology which has been developed and implemented has led to significant spinoff opportunities in more applied fields, and it is through this mechanism that ASTRON has been able to maximise its relevance for society and have positive impact on the nation and for Europe as a whole. In addition, ASTRON has played a leading role in conveying the excitement of astronomical discoveries to the public and in furthering STEM education, especially for women and other underrepresented groups.

In recent years, ASTRON has focused on developing and fielding new facilities in phased array radio interferometry. Their primary effort since the last review has been the construction and operation of the LOw Frequency ARray (LOFAR), which is a low frequency wide-aperture array, the premier such facility in the world in its domain. LOFAR has since expanded into the International LOFAR Telescope through partnering with eight additional countries in Europe, and enabling long baseline operations with significant gains in angular resolution. The institute is also in the midst of significantly upgrading its Westerbork Synthesis Radio Telescope (WSRT) facility through the development and integration of APERTIF (APERture Tile In Focus), a set of phased array feeds implemented on the existing WSRT dishes. APERTIF will provide a high efficiency widefield survey capability at higher frequencies, near 1 GHz, which will enable very sensitive, high resolution HI observations of much of the sky.

The science addressed by these capabilities is quite broad. Traditionally, this is the study of the formation and evolution of galaxies through observations of neutral Hydrogen. With the LOFAR telescope, this research found a natural extension into the Epoch of Reionisation, the cosmic period where stars and galaxies started to form. The study of Active Galactic Nuclei is another major research theme where multi-wavelength imaging observations are crucial to advance the field. Advances in digital signal processing made it possible to study rapidly varying phenomena in the Universe. Pulsar observations have been carried out with the WSRT since the 1990s; the fast multi-beam systems of LOFAR and WSRT-APERTIF have given pulsar surveys and the study of the transient universe an enormous boost. Ultimately, pulsar timing surveys will lead to independent observations of gravitational waves.

ASTRON has maintained and continues to recruit excellent scientific staff who are making pioneering observations in these disparate fields. The science programme is carried out together with university faculty groups. Notably, all of ASTRON's permanent astronomy staff have co-affiliations with a Dutch university.

ASTRON has also played a forefront role in advocating the science case and furthering the conceptual design of the Square Kilometre Array (SKA), a proposed worldwide effort to construct very large radio facilities in Australia and South Africa that will take this field to the next level. The ASTRON R&D department, in particular, has made significant contributions to the design and prototyping of key SKA subsystems in a range of areas. ASTRON is also coordinating the plan for Dutch involvement in SKA on behalf of the entire astronomical community. ASTRON was the initiating institution for SKA and continues to play an important role in the programme, contributing to the science case and system architecture, developing key subsystems and providing expert senior staff to serve on boards and advisory bodies.

In the technological R&D programme, ASTRON is careful to retain full end-to-end system capability. Three key focus areas here are (a) antennas and radio-frequency systems, (b) fast digital system processing, and (c) high-performance computing architectures and algorithms. In all areas, the focus is on studying, demonstrating and applying state-of-the-art technology. The actual development of systems is usually achieved via close collaboration with partners in universities and industry.

2.2 Research

Following its mission, ASTRON has three core departments:

The **Astronomy Group** contributes to ASTRON's mission in a variety of ways. The group takes a leadership role in next generation facilities through participation in science working groups and by acting as Primary Investigators. The group contributes to the development and subsequent full exploitation of the national facility telescopes by participation in science commissioning and by leading front-line science projects. The group has strong engagement with university-based astronomy groups in the Netherlands, through co-affiliations and shared appointments, participation in national committees and activities and in international scientific collaborations.

The **Radio Observatory** contributes to the mission of ASTRON focusing on the operation of world-class radio telescope facilities for the national and international community. The department was restructured in 2014 into three groups: Technical Operations & Maintenance, Software Support, and Science Support. Gradual rejuvenation and strengthening has taken place over the years in all three groups. The two telescopes of the Radio Observatory, LOFAR, and the WSRT, are in widely different stages of their lifecycles, and are also on a different operational and financial scales; consequently, the Radio Observatory's resources have been channelled predominantly to LOFAR.

The research and end-to-end design capabilities of the ASTRON **R&D department** are at the forefront of radio astronomy instrumentation development world-wide. Since the completion of the single pixel Multi-Frequency Front Ends for the WSRT, the focus of the department has shifted towards broad band phased array technology.

The R&D department has a leading role in the global research agenda towards a space-based facility for the lowest radio frequencies (100 kHz to 30 MHz) which cannot be observed with a ground-based telescope. Via a series of design studies (OLFAR, DARIS), a project is now being executed together with Radboud University and the SME ISIS with Chinese organisations to deploy an instrument on the Chang'E4 mission to the moon in 2018. The Netherlands-China Low-Frequency Explorer (NCLE) is considered to be a milestone for radio

astronomy since it is the first step towards a facility that will probe an unknown part of the electromagnetic spectrum.

Following the previous SEP evaluation in 2010, ASTRON had set the following strategic research targets:

- Enabling and supporting the optimal scientific exploitation of LOFAR and WSRT-APERTIF – telescopes that have the potential to make a major impact in many different areas of astrophysics.
- Continuing to play a crucial role in all aspects of the SKA project – taking the lead in at least one major pre-construction phase work-package (Aperture Arrays) and making a significant contribution to other aspects of the project, including Software & Computing.
- Development of innovative instrumentation for radio astronomy, in particular the deployment of a significant dense aperture array science demonstrator, operating at centimetre wavelengths (500- 1400 MHz) preferably as part of the SKA Advanced Instrumentation Programme (AIP), but otherwise as an independent effort.
- Strengthening the institute's own fundamental astronomy and technical research programme wherever possible; pursuing Dutch scientific leadership of at least one SKA Key Science Project, plus significant participation in others.
- Maintaining a viable R&D laboratory with in-house end-to-end system design capability, in order to build, test and deploy radio telescopes and significant demonstrators.

ASTRON's activities for 2017 - 2022 are aimed at making major progress towards its long-term vision. ASTRON's focus for the next five years is therefore:

1. Developing ASTRON's 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. Continuing 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 Netherland's participation in the SKA. This will be achieved via completion of 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. Realising new data management systems to allow the Dutch and wider astronomical communities to exploit LOFAR, WRST 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.

These five actions build on ASTRON's existing deep expertise and move into a future to ensure the institute remains a vibrant and important partner in the national and international research enterprise. Moreover, these endeavours further develop and maintain ASTRON's position in the mega-science arena, demonstrating Dutch excellence and capabilities within science facilities at the largest scale.

2.3 Organisational structure

The organisational structure of ASTRON follows the three core activities through which the mission is implemented. Figure 1 shows the organisation chart per April 2017.

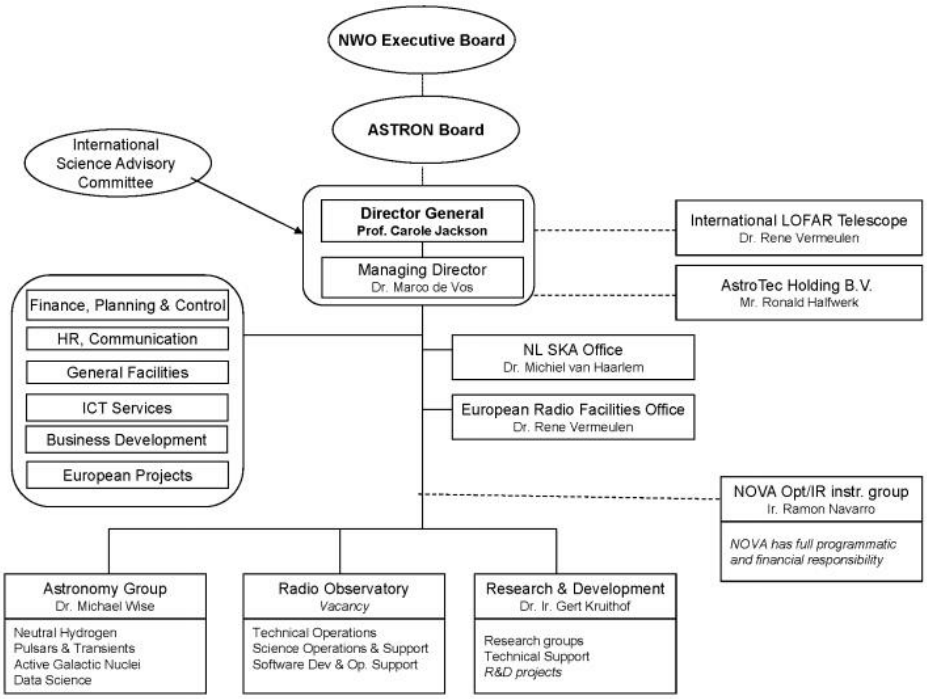

Figure 1. Organisation chart per April 2017

The ASTRON directorate consists of the Scientific & General Director and the Managing Director, reporting to the ASTRON Board and the NWO Director General.

The Astronomy Group (AG) is responsible for the astronomical research programme. Each of the focus areas has two or three staff astronomers associated with it. Staff astronomers are expected to raise funding for the research in their respective areas through ERC and NWO-VI grants, or through participation in larger H2020 projects. Members of the group play an important role in development projects as Primary Investigator or Project Scientist, as well as in the commissioning of new instruments and software.

The R&D department (R&D) is responsible for the technical research and development programme. The department is further organised along (technical) competence groups, covering the full range of areas needed for end-to-end systems development. Competence groups include scientific staff and engineers. The R&D department operates as a matrix organisation, executing both instrument development projects and pure technical research.

The Radio Observatory (RO) is responsible for the operations and support of LOFAR and WSRT-APERTIF. This includes technical operations and maintenance, science operations and support and operational software development and support. The Radio Observatory is the first contact point for internal and external users of ASTRON's facilities, providing support in all phases from proposal preparation, observation planning, data acquisition, initial processing and data retrieval. Radio Observatory staff are also responsible for quality control.

The NL SKA Office, reporting directly to the ASTRON Directorate, is responsible for the SKA programme, including maintaining relationships with academic stakeholders and government.

Several supporting functions enable the core departments to carry out their activities. These supporting functions are finance, planning & control (responsible for both financial administration and project control), human resources & communication (also responsible for public outreach), business development, facilities and ICT.

Additionally, ASTRON hosts several independent entities, such as:

- **JIVE**, the Joint Institute for VLBI ERIC (and its predecessor the JIVE Foundation), with a mission to operate and further develop the EVN VLBI Data Processor and to support EVN users and the operations of EVN as a facility in Europe (~30 FTE).
- The **NOVA** Optical/IR instrumentation group, formerly part of ASTRON's R&D department but since 2007 fully under the responsibility of NOVA, the Dutch research school for astronomy (~12 FTE).
- **AstroTec Holding BV**, a commercial company with ASTRON as the sole shareholder, used as one of the tools to valorise the research carried out at ASTRON through spin-offs and joint ventures.
- The International **LOFAR Telescope**, a foundation under Dutch law in which the European partners join forces for the operation and exploitation of the European LOFAR network.
- The **ASTRON & IBM Centre for Exascale Technology**, a public-private partnership jointly staffed by ASTRON, IBM NL and IBM Zurich Research Lab (~15 FTE in Dwingeloo and Zürich).

2.4 Financial matters

ASTRON receives a base budget from NWO, which has been roughly stable at 7 M€/yr during the period of this assessment. From 2007, the Ministry of Education, Science and Culture granted ASTRON an additional 2 M€/yr for the operations of LOFAR. In 2016, the Board of NWO decided to make this additional grant permanent, such that ASTRON's base budget should be considered as 9 M€/yr.

Additionally, ASTRON more than doubles the base budget through successful grants and contracts won in competition. Important sources of funding are:

- EC personal grants (ERC Starter, ERC Advanced)
- EC framework programmes (FP7, H2020), e.g. RadioNet, ASTERICS, AENEAS.
- NWO personal grants ("Vernieuwingsimpuls" with Veni, Vidi and Vici programmes)
- NWO investment grants (NWO-M, NWO-G) and Roadmap Large Research Infrastructures
- ESA tenders (mainly aimed at technology transfer), e.g. Galileo Monitoring
- Regional innovation programmes, e.g. SKA-TSM, SKA-NN, DOME.

The level of funding from framework programmes, investment grants and innovation programmes has remained approximately stable over the past six years, although notably funds from personal grants have more than doubled over this review period.

2.5 Staff

Figure 2 shows the distribution of staff over 2011-2016 per department. Appendix 1 of the self-assessment document presents detailed information on function groups, age-distribution and diversity.

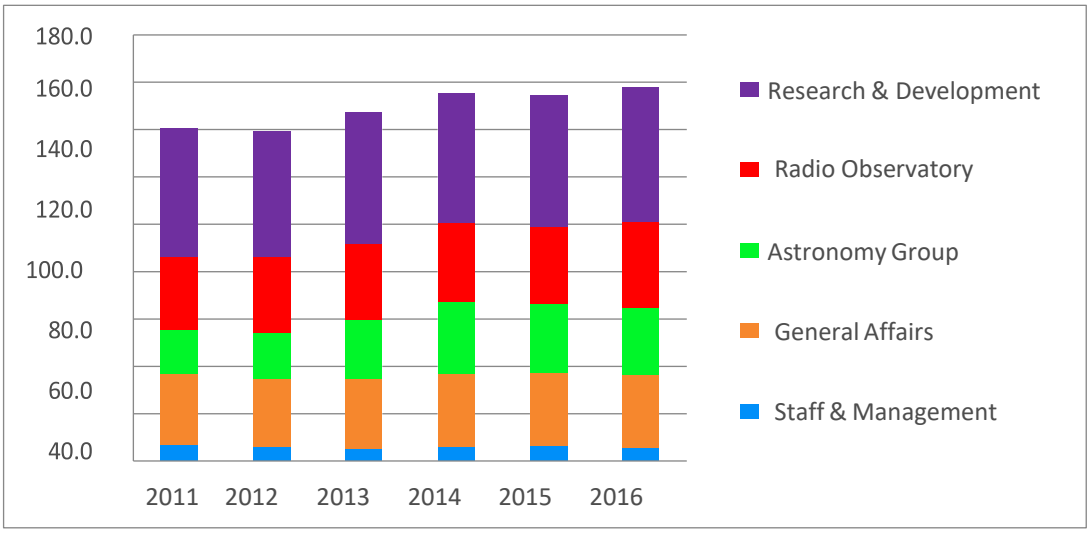

Figure 2: Staff numbers per department (2011-2016)

3 Assessment of ASTRON

3.1 Strategy and targets ASTRON

The stated strategy for the future involves a mix of both near-term and longer term goals:

(1) In the very near term, the highest priority will be the completion of APERTIF, and the operation of that facility for a four-year programme of survey observations. APERTIF should remain competitive with world facilities for roughly that timeframe, but its uniqueness and capability will decline after that, and thus it is essential that this facility be brought on-line as soon as possible, hopefully by the end of this calendar year.

(2) On somewhat longer timescales, the upgrade of LOFAR to LOFAR 2.0 will enhance the capabilities of that system, ensuring that it remains world leading for many years to come.

(3) The institute is also strongly focussing its scientific and technical workforce toward the broad topic of data science, motivated by the fairly large database (~ tens of Petabytes) already assembled by LOFAR, and anticipating the much larger databases that will be acquired by SKA. Foremost in the planning is the eventual development of a Science Data Centre (SDC) at ASTRON, which will form part of the SDC network for SKA as a whole, but will also meet the anticipated need of ensuring maximal science from LOFAR and APERTIF in the nearer term.

(4) Finally, underlying this whole strategy is the plan to lead the Netherlands into SKA, ensuring that Dutch scientists can play key roles in the initial phases of the SKA International Governing Organisation (IGO), and take leadership in appropriate areas of the SKA construction. A commitment from the Netherlands will be required in the 2019 timeframe, so even though the planning for the detailed implementation of SKA is still uncertain, it is essential that the scope of Dutch participation be worked out over the next few years.

In the view of this Committee, the strategy outlined above is very ambitious and scientifically meritorious. It is also well designed to maintain ASTRON at the forefront of the worldwide effort in radio astronomy. However, it will be a challenge to marshal the resources to actually make all this happen. The management of ASTRON may need to undertake a finer level of prioritisation to allow for the difficult decisions that might have to be made if the total desired funding does not materialise.

3.2 Research quality

Research at ASTRON is governed by the mission statement "Making Discoveries in Radio Astronomy Happen". This mission statement is driven by the ASTRON-led accessibility to world-class observatories such as LOFAR and WSRT/APERTIF and equally importantly by the innovative technology and personnel at ASTRON who are looking to the future.

The six-year span under review showed the observatory's three main divisions (R&D, RO and AG) working together to undertake and overcome incredible technical challenges with LOFAR especially, and very soon APERTIF, to produce true multi-purpose radio observatories with an incredible amount of science potential. Looking to the future, ASTRON is well situated to play a leading role in the upcoming SKA, especially SKA-Low and a next-generation science data centre.

LOFAR

Through visionary ASTRON leadership in instrumentation, calibration, imaging, and astrophysics, LOFAR has progressed through enormous technical challenges to emerge in recent years as a highly productive, world-class facility. The challenges of ionospheric calibration, imaging dynamic range, massive data rates, and radio frequency interference were all thought by many to be almost insurmountable, yet ASTRON has steadily dealt with each of these and other issues, and slowly ramped up the scientific productivity of the facility.

Two of the major challenges facing LOFAR at the beginning of the review period were tied to the enormous data rate produced, and the technical challenges of calibration and imaging for this new type of instrument. The magnitude of the data volume challenge is highlighted by the 31 PB currently in the Long Term Archive, making it the largest astronomical data collection currently existing. The ASTRON team has met the challenge of archiving the data and providing products to Key Science teams but they are still facing the challenges associated with bringing LOFAR data products to a wider community of users. The science data portal will be an invaluable resource for all ASTRON data collections, and will propel LOFAR scientific output within the broader community across the full range of astrophysics.

Technical challenges of calibration and imaging which are directly tied to data processing speed were met through innovative work at ASTRON on the development of direction-dependent calibration techniques required for low frequency aperture arrays, as well as the in-house development of the GPU-based (COBALT) correlator. Overall these advances have brought LOFAR processing from the stage of weeks or months per program to the stage of hours, thus enabling the world-class status LOFAR currently enjoys.

LOFAR is currently producing stunning images of radio galaxies at high resolution and dynamic range, showing structures never before seen, for example in the LOFAR Two-metre Sky Survey (LoTSS) (Shimwell et al. 2016). It is finding new pulsars that are exotic, such as both the fastest and slowest rotating known neutron stars in the Galactic disk (Bassa et al. 2017), as well as some of the nearest known neutron stars to the Earth.

It is allowing extremely precise measurements of the interstellar medium (Geyer et al. 2017), the solar wind (Fallows et al. 2012), and other forms of space weather, providing improved systematics for Pulsar Timing Arrays such as the EPTA and the IPTA (Hassal et al. 2012; Kondratiev et al. 2016), unique probes of ionised gas for astronomy and planetary science, and potentially early warnings about dangerous solar flares and coronal mass ejections – a valuable service for society. The increased pace of scientific productivity can be seen by the factor of 5 increase in scientific publications over the review period. This pioneering work on LOFAR has paved the way toward future generations of low frequency aperture arrays such as SKA-low, and important new pulsar, radio galaxy/AGN, and HI results, especially, are expected to emerge from LOFAR over the coming years.

While the Committee members were slightly surprised and disappointed with the lack of (published) progress in Epoch of Reionisation (EoR) studies with LOFAR, they also note the incredible difficulty of the measurement in general, and the insidious systematics from the telescope, atmosphere, and foregrounds that must be overcome. In addition, the recent loss of Ger de Bruyn – the definitive leader in ASTRON's LOFAR EoR efforts – has been a massive blow to the effort. Much progress has nevertheless been made by the group, as evidenced by the recent LOFAR paper on the topic, and the Committee has confidence that the excellent hiring of Harish Vedantham will help to push these efforts forward in the near future.

While LOFAR is most certainly a general purpose observatory, its EoR efforts and potential are widely recognised, and definitive results will be crucial to see in the near future. The Committee further notes that the on-going MSSS and LoTSS surveys will provide an invaluable resource to the astronomical community, and encourages the timely distribution of survey data products to users for full exploitation of the scientific potential of the data.

An impressive development over the course of this review is the enormous international attention and support for LOFAR as seen through the partner nations in the International LOFAR Telescope (ILT), which enables 14 stations spread across the Netherlands and another 7 countries with additional countries likely to join. The growth of the ILT highlights the desire of nations to be part of this world-class facility and its blossoming scientific productivity.

APERTIF

The challenges faced by the LOFAR team within ASTRON led to a resource shortage for completion of APERTIF. ASTRON has recently refocused resources in a dedicated push to complete the integration and commissioning of APERTIF. The Committee fully supports the APERTIF reprioritisation, as the time for these surveys is now.

These focal plane arrays will reposition WSRT as a world-class facility with dedicated imaging surveys providing HI spectral line data sets as well as radio continuum and pulsar/transient surveys. Despite the delays in completing APERTIF, many aspects of the project remain internationally competitive. ASKAP and MeerKAT will carry out southern-hemisphere HI surveys in the near future, but APERTIF has both a factor of two higher spatial resolution than ASKAP and a much larger field of view than MeerKAT. This gives APERTIF a significant advantage for large-area studies of resolved HI in nearby galaxies (an area of long-term scientific strength at ASTRON). APERTIF will also produce a northern-hemisphere HI survey with outstanding legacy value to the wider astronomy community. The APERTIF transient programme and Fast Radio Burst (FRB) search is at the front rank of international programmes in an important and fast-moving area of astrophysics, and the plan to use LOFAR for fast localisation of FRBs is novel and potentially transformational for this field.

The Committee noted that the phased array feed (PAF) development at ASTRON for this programme places them easily within the top two to three groups in the world. An excellent example of the innovative work from these efforts beyond APERTIF is the aperture array system EMBRACE, which likely represents the longer-term future of cm-wavelength radio astronomy.

SKA, SDC and the Future

Looking to the future, ASTRON has an ambitious programme of development to build on their success and expertise. This includes the upgrades to both the low band and high band portions of LOFAR to realise a powerful new LOFAR 2.0 instrument, the development of a SKA science data centre, and ASTRON has situated itself to play a defining role in the next generation of radio astronomy through their R&D roles in the upcoming SKA phase 1.

The Committee applauds ASTRON for its excellent recent scientific staff hires, who have the skills, motivation, and experience in many of the key areas of scientific promise for LOFAR – galaxies of all types in HI, pulsars and transients, and the EoR. The current scientific staff are doing excellent research with their own groups, with many graduate students throughout the Netherlands, and often as parts of high-profile international collaborations. These efforts have resulted in high-impact papers in Science and Nature (such as Vegetti et al. 2012, Morganti et al. 2013, Antoniadis et al. 2013, Tadhunter et al 2014, Keane et al. 2016, Spitler et al. 2016, Tremblay et al. 2016) and several grants which have benefited the observatory both directly with improvements for its facilities as well as indirectly by providing students

and postdocs. These metrics, as well as the obvious value that the Universities see in them given their ubiquitous joint appointments, show that the staff is truly world-class. And given the growth of the Astronomy Group over the past few years, especially via young hires, there is a huge amount of potential for the staff to produce excellent science with LOFAR and APERTIF and to lead the observatory into the age of the SKA.

Rating: 1

3.3 Relevance to society

As an NWO institute, a core element of ASTRON is focussed on maximising its impact on society and industry. This is achieved in a variety of ways.

Industry

ASTRON organises its projects such that companies can optimally collaborate and benefit from its high-tech developments. Several of ASTRON's systems are created in co-development with industry, for example research in exascale technology has been carried out in a public-private partnership with IBM. New requirements abstracted from science programmes became input for a joint research programme, the DOME project. The experience and technical progress developed from those projects were subsequently adapted and used by IBM in its other business fields.

Especially impressive has been ASTRON's ability to connect with local industry and SMEs. ASTRON has successfully formed partnerships with local industry through competitive contracts for critical technology. As an example, a nearby company (a subsidiary of NEWAYS) has provided more than 4000 electronic circuit boards for ASTRON in the past years. The LOFAR antennas and other mechanical parts are also manufactured in large quantities locally.

The local provincial government of Drenthe considers ASTRON a unique and valuable partner in this region. Not only because of ASTRON's international reputation, but primarily because of the positive influence on local industry in terms of innovation and exchange of high-tech skills, and the contribution to the general public in educating and inspiring the younger generation.

The Northern Provinces of the Netherlands have awarded a sum of 5.5M€ to ASTRON in the SKA design phase. This is an excellent indication of the value that the local community has placed on ASTRON's contributions to society.

Outreach

In each year of the period under evaluation, ASTRON organised an open day in October during Dutch Science Weekend. In connection with these open days, ASTRON organised lectures, laboratory visits, and site visits to WSRT and LOFAR. The number of participants at such open days is usually a few hundred. It gives the participants a unique opportunity to be closer to the astronomers and engineers, and also to be exposed to cutting edge technologies. ASTRON also organises yearly Girls' Days, specifically for high school girls. The girls can participate in experiments and talk to female scientists and engineers to get a feeling for the exciting world of astronomy and engineering.

ASTRON's efforts to communicate scientific knowledge to the general public are also presented in other forms, such as open lectures and exhibitions, which have been generally well attended.

In the Astronomy Group of ASTRON, many staff have teaching positions in the universities in the Netherlands. This reflects not only the excellence of ASTRON staff, but also the good

relationship between ASTRON and the national research community. Through LOFAR and WSRT, radio astronomical research in the Netherlands has increased significantly in the past 10 years. Indeed, many Dutch university professors have been involved in the construction of LOFAR and APERTIF, and the data exploitation of these instruments.

Finally, ASTRON hosts independent organisations, JIVE (Joint Institute for VLBI in Europe) and NOVA (Netherlands Research School for Astronomy, which is a collaboration of the astronomy groups at the Dutch universities). By hosting these two organisations, ASTRON is sharing both science and technology with them. These efforts have enhanced and also enlarged ASTRON's own experience, and its impact on the national and European research landscape. Both organisations feel comfortable and happy with the arrangement and the mutual benefits that it has brought.

Overall, the Committee considers ASTRON to be very successfully integrated into the Dutch astronomical community. As a radio astronomy institute, ASTRON has an impressive and unique record of attracting industrial partners. In addition, they have been very active and successful in linking with local government and the general public.

Rating: 1

3.4 Viability

In the view of the Committee, the existing leadership and organisational structure of ASTRON is well-positioned to lead this institute into the future. The present Director, Prof. Carole Jackson, has only been in place for six months, but it is already clear that she has provided the leadership and scientific judgment necessary to steer this institution through the challenging years ahead. She is very ably supported by her Managing Director, Dr Marco de Vos, who has been with ASTRON for many years, and by the others in her Management Team, Dr Michael Wise, Head of the Astronomy Group, and Dr Ir Gert Kruithof, the Head of the R&D Department. At present, the Head of the Radio Observatory is vacant, but the Committee was told that the search process to fill that position is well underway.

At present, roughly 50% of the funding for ASTRON comes from its base funding provided by NWO, with the remainder coming from limited term grants and contracts from a variety of sources. The institute has a very admirable record of attracting this form of competitive external funding, and it has been quite widespread, ranging from research grants in fundamental science, to contracts with industrial partners for shared technology development. External funding has been essential for the health and vitality of the R&D Department in particular, where more than half of their permanent staff are supported through such mechanisms. It has also enabled the growth of the Astronomy Group, especially through the attraction of younger scientists who have been supported partially through research grants. The Radio Observatory Department is the most dependent on base funding, as is to be expected, given that their primary responsibility is to operate existing facilities.

While it will be a challenge to maintain this level of external funding going forward into the future, the track record of the institute has been sufficiently impressive in this arena that the Committee has little doubt about the continuing financial viability of the institution. A different aspect of viability is associated with maintaining the quality of the scientific and technical staff, especially in the face of retirements that are inevitable over the next ten years. Indeed, the ASTRON workforce has aged slightly since the last review, but the institute has also hired some outstanding young people who appear to be well-poised to take on leadership roles for the future. Thus the Committee has high confidence that ASTRON can continue to perform at the highest level expected for the NWO institutes.

Rating: 1

3.5 Considerations regarding organisation, management policies and staffing

3.5.1 PhD programmes

ASTRON has an active program of PhD student training in astronomy and engineering. Since ASTRON is not a degree-granting organisation, all these students are enrolled at universities in the Netherlands or overseas and have an ASTRON staff member as a co-supervisor. The students spend varying amounts of time at ASTRON, typically visiting for one or two days a week to work with their ASTRON supervisors.

At the end of 2017, there were 29 PhD students working at ASTRON, 28 associated with the Astronomy Group, and 1 associated with the R&D group. This is an appropriate number as judged from comparisons to similar institutions elsewhere in the world. Appendix 3A (1) of the self-assessment report shows that there were 22 PhD completions between 2011-16 (an average of almost 4 per year). It is encouraging to see that most students are able to complete their PhD in four years or less.

Progress reviews for students are conducted by their home universities, and ASTRON has no formal Postgraduate Coordinator role. Erwin de Blok, who has responsibility for the ASTRON postdocs, currently acts as a contact point for the students if any issues arise. ASTRON does not offer additional training for PhD students. They are treated as part of the staff, and can follow courses that are available for staff members. NOVA organises schools and career planning events for students.

The Committee met with many of the PhD students. They all reported a very positive experience at ASTRON. Many of the students had come to ASTRON to work with a specific ASTRON staff member, but they also reported that they benefitted from the overall ASTRON environment in which astronomers and engineers work together, and the students have an opportunity to work with cutting-edge telescopes and facilities.

The previous Evaluation Committee suggested that ASTRON should increase the number of graduate students. There has been an increase in recent years, but the Committee believes there is still scope to bring in more students - especially given the recent recruitment of some outstanding new staff members in the Astronomy Group.

3.5.2 Research integrity policy

The research environment at ASTRON is in excellent shape. The R&D group follows a set of "core values" of 'Collaboration", "Responsibility", and "Customer Focus". Sophisticated testing methodologies are used at all levels of hardware and software development, as well as during scientific commissioning of telescopes and instruments.

In addition, mentioned in Section 3.6.1, ASTRON is committed to open access of data from their facilities and the opening of source code used for data acquisition and analysis, both of which dramatically improve the reproduce ability of science and help to maintain its integrity.

3.5.3 Diversity

ASTRON has an impressive geographical diversity among its staff members. While the majority of ASTRON's staff are Dutch, almost 25% of the staff are foreign nationals and they come from more than 20 different countries. ASTRON is to be congratulated for providing a welcoming, respectful and collegial working environment for staff from across the world.

The gender balance within ASTRON is improving through recent hires of several mid-career female astronomers. The Committee were given a more detailed breakdown of staff numbers in the first session of the meeting. Roughly 20% of ASTRON staff are women. 25% of ASTRON PhD students are female, and this is similar to the fraction across all Dutch astronomy PhD students. It was very encouraging to see that 40% of the postdocs, and 40% of support staff, are currently female. However, these are mainly short-term hires that do not generally lead to a longer-term staff position. Among the ASTRON engineering staff, however, there is still significant room for improvement.

The Evaluation Committee commends the initiatives that have already been taken to improve gender balance at ASTRON (including a female visitor scheme and a review of recruitment processes), and also recognises the geographical challenges presented by ASTRON's location at a significant distance from any major city. However, more could still be done to work towards improving gender balance – and both ASTRON and NWO could look at taking a targeted approach based on international best practice (e.g. schemes like Athena SWAN in the UK).

3.6 Supplementary questions by the NWO Executive Board

3.6.1 Generic questions

NWO formulated three additional questions in the Terms of Reference SEP-evaluation.

1. *What is the Institute's added value in the national context and its international position?*

Radio astronomy is one of the key areas of excellence for Dutch astronomy, due largely to the accomplishments of ASTRON over the last 60+ years. The continued health of ASTRON is vital to ensuring that the Netherlands retains its status in this field. Internationally, ASTRON has played a central role in conceptualising and performing early design work for the SKA, which will become the premier radio astronomy facility in the world for decades to come. ASTRON has also proven that through its innovative technology development programmes, it can catalyse significant technical and economic impact for the northern provinces, for the Netherlands, and for Europe as a whole.

2. *How does the Institute stimulate and facilitate knowledge utilization in open access?*

Astronomy, in general, is becoming more and more open with regard to making data available to others and to the sharing of increasingly important code and software used for data analysis, modelling, and simulation. ASTRON is following these trends and has committed to making telescope data publicly available after a proprietary time (usually 1 year) for the original investigators.

Similarly, the software and firmware used for astronomical observations and analysis is routinely made Open Source and available on modern source-code sites such as GitHub. The LOFAR data archive is an acknowledged weakness, though, and improvements to its interface should allow more and better access to the wealth of excellent data already archived.

3. *How does the Institute's structure, size and financial policy contribute to its mission?*

ASTRON is organised into three main groups that correspond to the core activities of the Institute: Astronomy, Research and Development, and Radio Observatory, each with its own head. Most ASTRON staff members are assigned to one of these groups, but there is some overlap in activities – for example, many of the Radio Observatory staff have astronomy

PhDs and carry out research projects in addition to their observatory support duties. Similarly, commissioning of a new instrument or facility will involve members of all three groups working as a team.

The Institute's structure appears to work well – ASTRON is one of only a handful of institutes worldwide with the capability for 'end-to-end' delivery of new and innovative capabilities for radio astronomy, from design through to in-house construction, commissioning, operation, and science results. The ASTRON building is well equipped, and its structure makes it easy for different groups to interact and collaborate.

ASTRON's staff numbers have grown slightly over the past five years, from about 140 to 160 personnel. This size is large enough to ensure that all three groups have a critical mass of expertise that allows them to perform at world-class level.

ASTRON's staff have a strong and consistent record of winning external grants and contracts to supplement the Institute's base level funding of 9 M Euros/year. These grants come from a diverse range of sources, and allow ASTRON to more than double the amount of funding available to support its activities. These external grants and contracts enhance almost all aspects of the Institute's mission – they support PhD students and postdoctoral researchers, strengthen regional innovation and development programmes like the DOME initiative, and provide access to a wide array of EU framework programmes.

3.6.2 Specific questions for ASTRON

NWO also formulated a specific question for ASTRON:

4. *Is ASTRON taking the right steps to prepare for the future in relation to the global SKA project?*

ASTRON has been leading the discussions, both within the Netherlands, and with the SKA Office in Manchester, over the details of Dutch involvement in SKA construction and science. Given the scale of the required investment, this has been difficult terrain to navigate, and there are still significant uncertainties that lie ahead before an agreement is finalised.

In particular, it is our understanding that the cost of membership at the desired level (~10%), coupled with the costs of ensuring that the Dutch community has the tools they will need to take leadership roles in SKA science, exceed the levels that can be comfortably borne by NWO and the Netherlands research science infrastructure programmes (National Roadmap for Large-scale Research Infrastructures). As such, this will require a major national commitment, on the scale of the Netherlands subscriptions to CERN and ESO.

The ASTRON leadership is well aware of these complexities, and has been working with its own Board and with university and industrial stakeholders to craft the appropriate case for such a substantial government commitment. We believe that the path they have chosen is on the right track, namely to select an appropriate suite of construction roles where ASTRON expertise is especially unique, to accompany that construction activity with the development of a Science Data Centre within the Netherlands, and to ensure that this can be all be accomplished without sacrificing ASTRON's current research programmes centered around LOFAR and APERTIF.

- ASTRON is responsible for two major research infrastructures (WSRT and LOFAR) that are being used by scientists from all over the world to do research and publish in high-ranking papers. ASTRON considers the role of its operational staff and support scientists to be essential for these results, but this cannot be made directly visible in publication rankings.

5. *Does ASTRON take sufficient action to make this contribution to scientific output visible and acknowledged?*

The scientists and staff working in the Radio Observatory, who perform most of the support work on the telescopes, develop extraordinary skill and knowledge about the instruments and observations that they support. Because of that skill, those staff are often asked to become co-investigators on observing proposals as well as authors on resulting publications. In addition, because these staff members all have some fraction of their time available for their own scientific research, their skills and knowledge directly aid their own proposals and publications.

We have learned that all new term appointments in the Radio Observatory now 50% science allocation. This is a very positive step. ASTRON should continue to encourage these actions, as well as to ensure that its support staff are able to actually get their specified fraction of research time. In a dedicated session, the panel discussed this topic with representatives from the Radio Observatory and the R&D divisions. In general, the staff felt adequately recognised and were mainly driven by curiosity and (technical) challenges. They receive much feedback and are encouraged to present their work at conferences. There is a formal track for annually looking back and evaluating past activities and planning for the coming year, including agreements on development.

4 Conclusions and recommendations

4.1 Conclusions

ASTRON is one of the top radio observatories in the world, and one of the few observatories of any kind with the ability to design, build, operate, and exploit world-class telescopes for astronomical research almost completely in-house. The staff and management team are excellent, and vibrant new hires are keeping ASTRON vigorous and preparing it for an exciting future. Over the last six years, they commissioned LOFAR and prepared the way for APERTIF, overcoming many difficult and technical challenges in the process, to produce one incredible facility in full scientific production and another ripe with potential.

In addition, they have prepared themselves to play a leading role in the upcoming SKA, especially in the technical development and science of SKA-Low, but also in data science and management.

The current ASTRON Director-General, Prof. Carole Jackson, has only been in place for six months, but it is already clear that she is having very positive impact on the institute. Among her early accomplishments has been a refocusing of effort onto APERTIF to ensure that that project is completed on a timeframe that will enable forefront science while WSRT/APERTIF is still competitive with other world facilities. She has also fostered a renewed emphasis on project management and systems engineering that will prove essential as ASTRON moves toward a construction project on the scale of SKA.

Prof. Jackson is ably assisted by her Managing Director, Dr Marco de Vos. Dr de Vos in particular has played an essential role in establishing strong relationships with industry and local Provincial Government. The remainder of her Management Team, consisting of Department Heads, Dr Michael Wise in the Astronomy Group, and Dr Gert Kruithof in the R&D Department, have exhibited strong visionary leadership skills that are well matched to their assigned roles.

Over the review period, LOFAR has transitioned to a highly productive world-class low frequency instrument which is now delivering transformational science across a broad range of scientific programmes. The ASTRON leadership in LOFAR has engaged an entirely new generation of radio astronomers and has been the catalyst for the international investment that has given rise to the powerful International LOFAR Telescope. LOFAR users both within and outside ASTRON universally attest to the exciting and scientifically revolutionary nature of the data from LOFAR. This world-class facility is a testament to the scientific and technical excellence displayed across ASTRON in the Astronomy Group, Radio Observatory Group, and Research and Development Group.

More recently, exciting progress has been made toward the completion of APERTIF which will drastically increase the survey speed of WSRT. This innovative focal plane array will turn the WSRT into an effective survey telescope with scientific applications such as deep imaging surveys of the northern sky of HI and OH emission, of the polarised continuum and efficient searches for pulsars and transients. Its unique specifications allow for a factor of two higher spatial resolution than ASKAP and a much larger field of view than MeerKAT, two other radio telescopes currently under construction.

ASTRON has excellent relations with key stakeholders, such as funding agencies, major international and local industries, Dutch universities and LOFAR/WSRT users. It is well integrated into the Dutch research landscape not only by design, building and operating the

national science facilities, such as LOFAR and WSRT, but also by being an important partner of the universities and local industries with leading scientific research capability and end-end innovative radio telescope system design and development capabilities. ASTRON has also contributed to the general public by sharing its scientific discoveries and knowledge through different activities such as open days, public lectures, exhibitions, etc. Therefore, ASTRON is well integrated in the Dutch research landscape.

Radio astronomy, or more specifically astronomy in general, is being driven by both technology and new discoveries to instruments that require international partnership to be realised. In such a landscape ASTRON and the Netherlands has and will continue to play an enormous international leadership role. In fact, Phil Diamond, the SKA Director General, commented that the Netherlands led by ASTRON "punches well above their weight" in the radio astronomy landscape. The technical and scientific excellence at ASTRON make them natural leaders in the next generation low frequency aperture array being developed for the Square Kilometre Array. It should be noted that the SKA Director General further noted that ASTRON was in fact the birth place of SKA and that the international community looks to ASTRON for leadership in this area. The world-class groups at ASTRON are ideally suited in experience, expertise and enthusiasm to take on the design and development challenges of LOFAR 2.0, the SKA and the new SKA Science Data centre.

It is essential that ASTRON take a strong leadership role in advancing Netherlands involvement technically and scientifically in SKA. We have been very impressed with the strong and unanimous support that prof. Jackson and her colleagues are receiving from the primary stakeholders: the astronomical community within the Netherlands and the international SKA Project Office personnel outside the country.

4.2 Recommendations

The recommendations are listed in no preferred order.

Research quality

We recommend that ASTRON continue to monitor closely the progress on the LOFAR measurement of the EoR Key Science Project Things appear to be progressing on the EoR Project team, but additional ASTRON efforts may be required to achieve definitive results as quickly as possible.

We recommend additional emphasis to be placed on timely delivery of a fully functional ASTRON Data Portal.

We fully endorse the addition of the Data Science Group within the Astronomy Group structure.

We recommend that ASTRON put even more attention to the enhancement of the system engineering skills. This includes professional project management, requirements definition and flow down systems design, and formal risk management and mitigation.

We strongly recommend that ASTRON and its university partners develop a more science-driven rationale for LOFAR 2.0. It is vital that the key science for this instrument remains internationally competitive in an era of major facilities like SKA1-LOW, JWST, ELT and ALMA.

We recommend that ASTRON compile and maintain a complete database of all publications, student thesis and other research output that result from the use of ASTRON facilities.

Relevance to society

We recommend that ASTRON take pro-active action to enhance its visibility in the local community, given the role that it plays for technology transfer and furtherance of STEM education. This could include more public talks and other public outreach activities.

We recommend that, given the community-driven nature of the current Dutch science agenda, NWO should provide some dedicated funding to ASTRON and other NWO institutes to ensure that they can be effective public communicators of science.

We recommend that ASTRON continue to explore utilising LOFAR as a 24-7 data service for space weather. Closer connections should be made with the space weather community to understand the science requirements of this community.

Viability

We recommend that ASTRON work with its partners in the Dutch universities, in Dutch industry, and with the SKA Project Office to agree on a concise set of talking points that clearly articulate the strongest possible case for this massive investment. With a new government in place, it will be essential that the message be clear, convincing, and consistent from all parties.

We recommend that ASTRON adopt formal risk management methodologies to assess the risks of not meeting some of its desired goals, due particularly to budget shortfalls. This should include a clear basis for prioritisation if difficult decisions have to be made. We suggest that the management team work these out ahead of time so that they can deliver cohesive messaging to their staff and stakeholders in order to control expectations.

We recommend that ASTRON adopt a more formal approach to mentoring of its junior staff, including students, postdocs and early career scientists and engineers.

We recommend that ASTRON maintain the continuing assessment of its technical skill base and its appropriateness to its evolving scientific and technical portfolio. This should be a component of succession planning for all key positions.

PhD programmes

We recommend that ASTRON appoint a staff member with formal oversight of the PhD-student programme (across both astronomy and engineering), to ensure that there is a holistic view of the PhD program across ASTRON, and that all students have access to appropriate training and mentoring.

We recommend that ASTRON work with Dutch and international universities to increase the number of PhD students co-supervised by ASTRON staff.

Research integrity

We recommend that ASTRON continue to take a very clear and unambiguous stance on the importance of research integrity and effectively communicate this core value to their staff and community.

Diversity

We recommend that ASTRON take a more proactive and professional approach (informed by international best practice) to creating change. We suggest that the promotion of diversity and gender balance is recognised as a key responsibility of all senior management.

We recommend that NWO establish a training program in diversity for senior leaders across all its institutes.

Annex 1. Curricula Vitae of Evaluation Committee Members

Prof. Steven Kahn (Chair)

Steven M. Kahn is the Cassius Lamb Kirk Professor in the Natural Sciences at Stanford University, and the Director of the Large Synoptic Survey Telescope (LSST), a large-aperture wide-field ground-based optical telescope now under development. He has previously served as the Associate Laboratory Director of SLAC National Accelerator Laboratory, and as the Chair of the Physics Departments at Stanford and Columbia Universities. He has also served as the Director, Deputy Director, or Associate Director of major interdisciplinary research laboratories at three universities, the Kavli Institute for Particle Astrophysics and Cosmology at Stanford, the Columbia Astrophysics Laboratory at Columbia, and the Space Sciences Laboratory at Berkeley. He has made significant contributions to X-ray astronomy, specifically with respect to high resolution X-ray spectroscopy of cosmic sources. He was the US Principal Investigator for the development of the Reflection Grating Spectrometer, which is currently flying on the European Space Agency¹s XMM-Newton Observatory.

In recent years, he has focused his efforts on experimental cosmology, specifically weak gravitational lensing, which is one of the prime scientific directions for LSST. Kahn is a Felllow of the American Physical Society, the American Association for the Advance of Science, and the American Academy of Arts and Sciences.

Prof. Tracy Clarke

Tracy Clarke is a research astronomer in the Remote Sensing Division at the US Naval Research Laboratory, Washington DC. She obtained her first degree in Astrophysics (1994) and her PhD (1999) at the University of Toronto. Thereafter, she held the Jansky Fellow position at National Radio Astronomy Observatory's Very Large Array (VLA) in Socorro, New Mexico. The Jansky Fellowship Programme supports outstanding postdoctoral scientists whose research is broadly related to the mission and scientific goals of the world-class research facilities operated by the National Radio Astronomy Observatory.

She then moved on to a postdoctoral position at the University of Virginia for a period of two years. In 2004, she continued her career as a research astronomer at Interferometrics (Naval Research Laboratory) during six years, after which she took up her current position (2010) as a research astronomer at the Naval Research Laboratory, in the Remote Sensing Division.

The Remote Sensing Division conducts a programme of basic research, science, and applications aimed at the development of new concepts for sensors and imaging systems for objects and targets on the Earth, in the near-Earth environment, and in deep space. She was the System Scientist during the development and construction of the first station of the Long Wavelength Array (LWA1) and is currently the Project Scientist for the VLA Low-band Ionosphere and Transient Experiment (VLITE) which is a commensal low frequency observing system operating on the VLA.

Prof. Scott Ransom

Prof Scott Ransom is a tenured astronomer with the National Radio Astronomy Observatory (NRAO) in Charlottesville, VA where he studies all things "pulsar". He is also a Research Professor with the Astronomy Department at the University of Virginia where he has several graduate students and teaches the occasional graduate class. He works on a wide variety of projects involving finding, timing, and exploiting pulsars of various types, using data from many different instruments and at energies from radio waves to gamma-rays.

Scott was awarded a Hertz Foundation Fellowship for a PhD while in his last year as a cadet at West Point. He completed a Master's degree in Astronomy at Harvard, and completed his PhD thesis on "New Search Techniques for Binary Pulsars" in 2001. After his PhD, he was a Tomlinson post-doctoral fellow at McGill University in Montreal, Canada until 2004 where he moved to NRAO as a staff astronomer. In 2006 he won the Bart J. Bok prize which is awarded for "distinguished research by a Harvard Astronomy Ph.D. recipient under age 35", and in 2010 he won the American Astronomical Society's Helen B. Warner Prize "for a significant contribution to observational or theoretical astronomy during the five years preceding the award." He is a Fellow of the American Physical Society and has authored or co-authored over 175 refereed publications including 15 in Nature or Science.

Prof. Elaine Sadler

Prof Elaine Sadler is a Professor of Astrophysics in the School of Physics at the University of Sydney and Director of the ARC Centre of Excellence for All-sky Astrophysics (CAASTRO). She has an undergraduate degree in Physics from the University of Queensland and a PhD in Astronomy from the Australian National University, and has held postdoctoral fellowships in Germany (at the European Southern Observatory, ESO) and the United States (at the National Optical Astronomy Observatories, NOAO). Much of her research is based on the analysis of data from large-area optical and radio surveys of the sky, and she has been involved in designing and carrying out several major astronomical surveys in the southern hemisphere. She currently leads the First Large Absorption Survey in HI (FLASH) project, which uses the new Australian SKA Pathfinder (ASKAP) telescope in Western Australia to identify and study neutral hydrogen gas in very distant galaxies.

Prof. Sadler has served as President of Division VIII (Galaxies and the Universe) of the International Astronomical Union (2009-2012), Chair of Australia's National Committee for Astronomy (2010-2012), Member-at-Large of the ESO Scientific and Technical Committee (STC, 2009-14) and Chair of CSIRO's Australia Telescope Steering Committee (2016-18). She was elected as a Fellow of the Australian Academy of Science in 2010, and is currently a member of the Academy's governing Council.

Prof. Ji Wu

Prof Ji Wu is a Professor of National Space Science Center, Chinese Academy of Sciences, Beijing, China. Professor Wu has been leading a team in developing several innovative interferometric imaging systems, such as Fully Polarized Interferometric Radiometer (FPIR) proposed for future Chinese space science missions for water cycle observation and SMOSops of ESA, Geostationary Interferometric Millimeter wave atmospheric Sounder (GIMS) for China's geostationary meteorological satellite FY-4M, etc. He also leads several important space science missions where remote sensing instruments are on board, such as, Chang'E-1, -2 and -3, Double Star Programme and missions in Chinese strategic priority programme on space science. In 2010, he and his team had been awarded the Laurels for Team Achievements Award by International Academy of Astronautics.

Wu obtained his Ph.D. degree from Technical University of Denmark. After that he came back to China and joined the National Space Science Center, the Chinese Academy of Science, where he is now the Director General. He is also the chair of Beijing Chapter of IEEE Geoscience and Remote Sensing, general co-chair of the International Geoscience and Remote Sensing Symposium 2016 in Beijing and vice president of COSPAR. Wu is also a full member of International Academy of Astronautics, and member of the Electromagnetics Academy.

He was named an IEEE Fellow in 2014. He is being recognized for leadership in microwave remote sensing and its application to satellite programmes. Key technology has been developed under his leadership and direct contribution is the passive microwave interferometric imaging which made China became one of the leading nations in this research area.

Annex 2. Programme of the Site Visit

Tuesday, 10 October 2017 - Day before the site visit (pre-meeting)

Committee arrives in the Netherlands, transport to Dwingeloo (hotel Wesseling)

- Committee meeting in the afternoon starting at 15:00 to 18:00; installing of the committee by a member of the Executive Board of NWO; short presentations about the Dutch science system, about the governance of the NWO institutes, and about the NWO 'transition' to its new organization structure and governance.
- Private Committee kick off (closed session): to discuss the assessment procedure, the Terms of Reference, and the procedure of writing the assessment report; to share information about the disciplinary expertise represented in the Committee; to discuss findings based on the material received prior to the site visit such as the self-assessment report; to prepare for tasks during the site visit.
- Dinner

Wednesday, 11 October 2017 - site visit Day 1

Institute and main research lines *(Oort room)*

Brief presentations by Management Team members and questions from the panel

09:00	Mission, institute highlights	Prof Carole Jackson (General & Scientific Director)
09:45	Industry, Societal impact, valorization	Dr Marco de Vos (Managing Director)
10:20	Coffee break *(outside Oort room)*	
10:35	R&D	Dr Gert Kruithof (Head R&D)
11:05	Astronomy Group	Dr Michael Wise (Head Astronomy Group)
11:35	Radio Observatory	Ing Marco Drost, Jasper Annyas, Dr Roberto Pizzo (Radio Observatory group leaders)
12:05	International LOFAR Telescope	Dr René Vermeulen (Director ILT)
12:20	SKA	Dr Michiel van Haarlem (Head NL SKA Office)

12:40 Lunch with PhD students (open & closed session) *(Hooghoudt room)*

Amruta Jaodand, Marisa Brienza, Francesco Santoro, Samayra Straal, Pedro Salas Munoz, Christiana Spingola, Martijn de Vries, Bram Veenboer, Georgi Kokotanekov

13:30 ***Tour of science, technology and laboratories***

Panel meets astronomy/technical staff

13:30 Central hall (exhibit table microserver/algorithms): *(20 min.)*

Prof Stefan Wijnholds (Algorithm Researcher)

Chris Broekema, MSc (HPC Expert)

Dr Ir Albert Jan Boonstra (Scientific Director DOME) – about DOME

13:50 Photonics lab: *(10 min.)*

Dr Peter Maat (Photonics Researcher)

14:00 Antenna Measurement Room/Faraday Cage *(10 min.)*

Ir Jan-Geralt Bij de Vaate (Project Manager)

14:10 Analog lab: *(10 min.)*
Dr Ir Albert Jan Boonstra (Program Manager Technical Research) - about NCLE
14:20 Digital lab: *(15 min.)*
Ir André Gunst (Head Digital & Embedded Systems Group)
14:35 Control room: *(20 min.)*
Dr Roberto Pizzo (Head Science Operations Support)
Dr Ir Jan David Mol (Software Architect)
Dr Vanessa Moss (Junior Telescope Scientist)
Jurjen Sluman (Operator)
14:55 Mechanical workshop: *(10 min.)*
Ing Paula Fusiara MA (Mechanical Engineer, ASTRON)
15:05 NOVA Group (10 min.)
Ir Gabby Kroes (NOVA Lead Engineer)
15:15 JIVE Correlator Room: *(15 min.)*
Prof Huib-Jan van Langevelde (JIVE director)

15:30 Tea *(outside Oort room)*

15:45 Research highlights - four presentations by staff astronomers: *(Oort room)*
open session with 10 minutes presentation and 5 minutes question time; followed by a closed session
Dr Jason Hessels
Dr Gemma Janssen
Dr Betsey Adams
Dr Timothy Shimwell

17:15 Return to Hotel
17:45 Closed session
19:30 Dinner

Thursday 12 October – site visit Day 2

Stakeholders and governance, WSRT+LOFAR visit

Interviews and meetings (Oort room)

09:00 Interview with business partners and regional stakeholders
Mr Peter Zijlema (CEO IBM Benelux)
Mrs Monique Leijn (Economic affairs, Province of Drenthe)
Mr Michel Postma (Managing Director, Neways Leeuwarden)

09:30 Interview with selected LOFAR/WSRT users
Prof Anna Scaife (Univ Manchester)
Prof Thijs van der Hulst (University of Groningen)
Prof Leon Koopmans (Univ Groningen)
Prof Dominik Schwarz (Univ Bielefeld)

10:00 SAC representatives
Prof Sean Dougherty (SAC Chair, DRAO)
Prof Huub Röttgering (Univ Leiden)

Prof Leon Koopmans (Univ Groningen)

10:30 Coffee *(outside Oort room)*

10:50 SKAO Director General Prof. Phil Diamond - video link

11:30 ASTRON Board representatives
Prof Karel Gaemers (chair)
Prof Johan Bleeker
Drs Sipke Swierstra

12.00 Lunch/Closed session *(Oort room)*

13:00 EU H2020 representative: Dr Fabio Pasian (Chair ASTERICS Board - video link)

13:30 Travel to WSRT (with Management Team / selected staff, including technical staff)
14:00 *WSRT tour* - technical staff: Lute van de Bult / 5 panel members + Maaike Damen (NWO, internal secretary) + Daphne den Hollander (Birch Consultants, external secretary)
Apertif:
Prof Tom Oosterloo (co-PI Apertif)
Dr. Joeri van Leeuwen (PI Apertif ARTS)
Nico Ebbendorf (Head Technical Support Group)
M.Sc. Boudewijn Hut (Junior commissioning engineer)
Ing Marco Drost (Head Technical Operations)

15:00 Travel to LOFAR
15:30 *LOFAR Core tour* / 5 panel members + Maaike Damen (NWO, internal secretary) + Daphne den Hollander (Birch Consultants, external secretary)
Dr René Vermeulen (Director International LOFAR Telescope)
Dr Michiel Brentjens (Associate Observatory Astronomer)

16:30 Travel to hotel
17:30 Closed session (1 hour closed session)
19:00 Dinner

Friday 13 October – site visit Day 3

08:30 Diversity Committee: *(Oort room)*
Dr Betsey Adams (chair) Dr Tammo Jan Dijkema
Mrs Janneke Wubs-Komdeur

09:00 Workers Council representatives: *(Oort room)*
Dr André Offringa (chair)
Mrs Ingrid Arling (vice-chair)
Ir Marcel Loose (secretary)

09:30 Poster session (Postdocs Astronomy Group + Radio Observatory) *(Central Hall 2012)*
Dr Robert Schulz, Dr Bjorn Adebahr, Dr Marco Iacobelli, Dr Sarrvesh Sridhar,

Dr Emily Petroff, Dr Aleksandr Shulevski, Dr Antonino Marasco, Dr Jeremy Harwood, Dr Raymond Oonk, Dr Vlad Kondratiev, Dr Yogesh Maan, Mark Kuiack (PhD student Univ Amsterdam)

10.45 Open Door Session *(Hooghoudt room)*
include support staff:
Finance, Planning & Control: Mrs Janneke Wubs-Komdeur
HR & Communication: Mrs Diana Verweij

11:30 Closed session (incl lunch) preparing for the preliminary feedback and the evaluation report *(Oort room)*

15:15 Preliminary feedback to the ASTRON directorate + Dr Ir Christa Hooijer (on behalf of NWO Executive Board) + Prof Karel Gaemers (chair ASTRON Board) *(Oort room)*

16:00 End of site visit
Informal drinks offered by ASTRON *(outside Oort room)*

Annex 3. Explanation of the SEP-categories

The committee assesses the institute on the three assessment criteria: research quality, relevance to society and viability. These criteria are assessed both in qualitative terms (with arguments) and quantitative terms (in one of the four categories, see the table below).

Table 1. Meaning of categories in SEP 2015-2021

Category	Meaning	Research quality	Relevance to society	Viability
1	World leading / excellent	The institute has been shown to be one of the few most influential research groups in the world in its particular field.	The institute makes an outstanding contribution to society.	The institute is excellently equipped for the future.
2	Very good	The institute conducts very good, internationally recognised research.	The institute makes a very good contribution to society.	The institute is very well equipped for the future.
3	Good	The institute conducts good research.	The institute makes a good contribution to society.	The institute makes responsible strategic decisions and is therefore well equipped for the future.
4	Unsatisfactory	The institute does not achieve satisfactory results in its field.	The institute does not make a satisfactory contribution to society	The institute is not adequately equipped for the future.

In addition to the three criteria, every assessment also considers at least three further aspects: PhD programmes, research integrity, and diversity. These aspects are only assessed in qualitative terms.

Annex 4. Terms of Reference

The board of The Netherlands Organisation for Scientific Research (NWO) hereby issues the following Terms of Reference to the assessment Committee of ASTRON, chaired by Prof. Steven Kahn.

Topic	Description
Title	External evaluation of ASTRON of the period 2011 – 2016
Why	NWO organises periodic evaluations of each research institute within the organisation every six years. This is part of the standing agreement with the Ministry of Education, Culture and Science. Together with Royal Netherlands Academy of Arts and Sciences (KNAW) and the Association of Universities in the Netherlands (VSNU), NWO has stated to conduct these evaluations according to the Standard Evaluation Protocol (SEP). The goal of the periodic assessments is primarily to identify the quality of the research and the societal relevance and secondly to - partly on the basis of the assessment results - determine the mission and the basic funding for the next six years (2018-2023).
What	The assessment committee evaluates quality and relevance to society of the research conducted by the institute as well as its strategic targets and the extent to which it is equipped to achieve them. The committee does this by judging the institute's performance on the three SEP assessment criteria, taking into account current international trends and developments in science and society in the analysis. Each criterion should receive a ranking in one of the four categories in accordance with the SEP guidelines. The committee also ensures that the qualitative assessment (text) and the quantitative assessment correspond. Furthermore, the committee should give recommendations for improvement. **The three SEP assessment criteria are**: - **Research quality** - **Relevance to society** - **Viability.** The assessment committee also gives a qualitative evaluation on three **additional aspects**: - **PhD programmes** - **Research Integrity** - **Diversity** Further information about the criteria and additional aspects can be found in chapter 2 of the Standard Evaluation Protocol (SEP). **In addition to the topics above NWO has formulated three questions**: 1. What is the institute's added value in the national context and its international position? 2. How does the institute stimulate and facilitate knowledge utilization and open access? 3. How does the institute's structure, size and financial policy contribute to its mission? **For this particular institute NWO has also formulated the following specific topics**: - Is ASTRON taking the right steps to prepare for the future in relation to the global SKA project? - Acknowledgement of the role of support: ASTRON is responsible for two major research infrastructures (WSRT and LOFAR) that are being used

	by scientists from all over the world to do research and publish in high-ranking papers. ASTRON considers the role of its operational staff and support scientists to be essential for these results, but this cannot be made directly visible in publication rankings. Does ASTRON take sufficient action to make this contribution to scientific output visible and acknowledged?
For whom	- The researchers themselves in order to establish where they stand, how they can improve and what the research should aim for. - The management of the institute who wishes to track the impact of their policy. - The board of NWO who decides on the accountability of the institute and the support for the institute. - Other stakeholders from, for example, the society and private sector. - The Ministry of Education, Culture and Science has requested a portfolio analysis of all the research institutes of NWO and the Royal Netherlands Academy of Arts and Sciences in 2018. The results of the SEP-evaluations will act as input for this portfolio analysis.
Who	The independent assessment committee consists of 4-7 renowned international experts within the realm of the institute. Each committee member signs a statement of impartiality and confidentiality.
How	The assessment committee will be supported by a liaison officer from NWO and an independent secretary. The necessary documentation to conduct the assessment will be made available to the committee one or two months before the site visit. This documentation includes at least a self-evaluation by the institute, a strategy document of the institute and the conclusions and recommendations from the previous assessment. If feasible the institute may provide a bibliometric analysis or a different study of its own choice to support the self-evaluation. The assessment committee will be invited to the institute for a site visit of three days during which the institute will present itself in short lectures and interviews by the committee. The assessment committee will deliver a draft evaluation report to the NWO board no later than eight weeks after the site visit and a final version no later than 12 weeks after the site visit. Finally, the NWO board will publish the assessment report on the website accompanied by a public statement.
When	The site visit will take place in September or October 2017. NWO distributes the necessary information and documents to the committee 1 or 2 months in advance of the site visit. For further information on the general time schedule please refer to the attached Standard Evaluation Protocol.
Contact	Daphne den Hollander MSc (Dialogic/Birch) and Dr Maaike Damen (NWO)

Necessary documents that will be made available to the assessment committee:

- Self-evaluation 2011-2016
- Strategy document
- Further description of what the committee needs to know about the scope/context, assessment questions, method, time schedule, final report
- Programme of the site visit
- Standard Evaluation Protocol (SEP)
- Conclusions and recommendations from previous evaluation
- Response NWO to the previous evaluation report
- <optional> Bibliometric analysis