MASTER'S PROGRAMME ASTRONOMY

FACULTY OF SCIENCE

LEIDEN UNIVERSITY

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Project number: Q0727
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This report was finalised on 23 september 2019

REPORT ON THE MASTER'S PROGRAMME ASTRONOMY OF LEIDEN UNIVERSITY

This report takes the NVAO's Assessment Framework for the Higher Education Accreditation System of the Netherlands for limited programme assessments as a starting point (September 2018).

ADMINISTRATIVE DATA REGARDING THE PROGRAMME

Master's programme Astronomy

Name of the programme:	Astronomy
CROHO number:	60200
Level of the programme:	master's
Orientation of the programme:	academic
Number of credits:	120 EC
Specialisations or tracks:	Astronomy Research Astronomy and Cosmology Astronomy and Data Science Astronomy and Instrumentation Astronomy and Business Studies Astronomy and Science Communication and Society Astronomy and Education
Location:	Leiden
Mode of study:	full time
Language of instruction:	English
Submission deadline NVAO:	01/11/2019

The visit of the assessment panel Physics and Astronomy to the Faculty of Science of Leiden University took place on 23 and 24 April 2019.

ADMINISTRATIVE DATA REGARDING THE INSTITUTION

Name of the institution:	Leiden University
Status of the institution:	publicly funded institution
Result institutional quality assurance assessment:	positive

COMPOSITION OF THE ASSESSMENT PANEL

The NVAO has approved the composition of the panel on 1 February 2019. The panel that assessed the master's programme Astronomy consisted of:

- Prof. dr. R. (Reinder) Coehoorn, full professor at the Eindhoven University of Technology, on the Physics and Application of Nanosystems. He is affiliated to the research group Molecular Materials and Nanosystems, in the Department of Applied Physics [chair];
- Prof. dr. M.J. (Margriet) Van Bael, professor at the Department of Physics and Astronomy of the Faculty of Science of the KU Leuven (Belgium);
- Prof. dr. G. (Garrelt) Mellema, professor and programme director at the Department of Astronomy of Stockholm University (Sweden);
- Prof. dr. S. (Sjoerd) Stallinga, professor and head of the Department Imaging Physics of Delft University of Technology;
- L. (Laura) Scheffer BSc, master's student Physics at Utrecht University [student member].

The panel was supported by P. (Peter) Hildering MSc, who acted as secretary.

WORKING METHOD OF THE ASSESSMENT PANEL

The master's programme Astronomy at the Faculty of Science of Leiden University was part of the cluster assessment Physics and Astronomy. Between April 2019 and June 2019 the panel assessed 17 programmes at 5 universities.

Panel members
The panel consisted of the following members:

- Prof. dr. R. (Reinder) Coehoorn, full professor at the Eindhoven University of Technology, on the Physics and Application of Nanosystems. He is affiliated to the research group Molecular Materials and Nanosystems, in the Department of Applied Physics [chair];
- Prof. dr. M.J. (Margriet) Van Bael, professor at the Department of Physics and Astronomy of the Faculty of Science of KU Leuven (Belgium);
- Prof. dr. H.A.J. (Harro) Meijer, professor of Isotope Physics, chairman of the Centrum voor Isotopen Onderzoek (CIO) and director of the Energy and Sustainability Research Institute Groningen at University of Groningen;
- Prof. dr. G. (Garrelt) Mellema, professor and programme director at the Department of Astronomy of Stockholm University (Sweden);
- Prof. dr. S. (Sjoerd) Stallinga, professor and head of the Department Imaging Physics of Delft University of Technology;
- Prof. dr. G. (Geert) Vanpaemel, professor for History of Science and Science Communication at KU Leuven, Belgium;
- J. (Jeffrey) van der Gucht BSc, master's student Physics and Astronomy at Radboud University [student member];
- B. N. R. (Bram) Lap BSc, master's student Astronomy at University of Groningen [student member];
- L. (Laura) Scheffer BSc, master's student Physics at Utrecht University [student member].

For each site visit, assessment panel members were selected based on their expertise, availability and independence.

The QANU project manager for the cluster assessment was Peter Hildering MSc. He acted as secretary in the site visit of Leiden University. In order to assure the consistency of assessment within the cluster, the project manager was present at the panel discussion leading to the preliminary findings at all site visits and reviewed all draft reports. Dr. Barbara van Balen acted as secretary in the site visits of University of Groningen and the joint degrees in Amsterdam. Drs. Mariëtte Huisjes was secretary at Radboud University, and Dr. Marijn Hollestelle at Utrecht University. The project manager and the secretaries regularly discussed the assessment process and outcomes.

Preparation
On 24 January 2019 the panel chair was briefed by the project manager on the tasks and working method of the assessment panel and more specifically his role, as well as use of the assessment framework.

A preparatory panel meeting was organised on 15 March 2019. During this meeting, the panel members received instruction on the tasks and working method and the use of the assessment framework. The panel also discussed their working method and the domain specific framework.

A schedule for the site visit was composed. Prior to the site visit, representative partners for the various interviews were selected. See Appendix 4 for the final schedule.

Before the site visit, the programmes wrote self-evaluation reports of the programmes and sent these to the project manager. He checked these on quality and completeness, and sent them to the panel members. The panel members studied the self-evaluation reports and formulated initial questions and remarks, as well as positive aspects of the programmes.

The panel also studied a selection of theses. The selection existed of 12 theses and their assessment forms for the programmes, based on a provided list of graduates between 2016-2018. For this selection, the panel used the opportunity to select a lower number of theses as described in the NVAO framework in the case of significant overlap between the assessed programmes in a single site visit. In the case of the master's programme Astronomy, this overlap consists of a shared Board of Examiners with the bachelor's programme Astronomy, as well as alignment of assessment procedures with the Physics Board of Examiners and internal benchmarking through an overlap of teaching staff with the other programme's in the assessment. A variety of topics and tracks and a diversity of examiners were included in the selection. The project manager and panel chair assured that the distribution of grades in the selection matched the distribution of grades of all available theses.

Site visit
The site visit to Leiden University took place on 23 and 24 April 2019.

At the start of the site visit, the panel discussed its initial findings on the self-evaluation reports and the theses, as well as the division of tasks during the site visit.

During the site visit, the panel studied additional materials about the programmes and exams, as well as minutes of the Programme Committee and the Board of Examiners. An overview of these materials can be found in Appendix 5. The panel conducted interviews with representatives of the programmes: students and staff members, the programme's management and representatives of the Board of Examiners. It also offered students and staff members an opportunity for confidential discussion during a consultation hour. No requests for private consultation were received.

The panel used the final part of the site visit to discuss its findings in an internal meeting. Afterwards, the panel chair publicly presented the panel's preliminary findings and general observations.

Report
After the site visit, the secretary wrote a draft report based on the panel's findings and submitted it to the project manager for peer assessment. Subsequently, the secretary sent the report to the panel. After processing the panel members' feedback, the project manager sent the draft reports to the faculty in order to have these checked for factual irregularities. The project manager discussed the ensuing comments with the panel's chair and changes were implemented accordingly. The report was then finalised and sent to the Faculty of Science and University Board.

Definition of judgements standards
In accordance with the NVAO's Assessment framework for limited programme assessments, the panel used the following definitions for the assessment of the standards:

Generic quality
The quality that, from an international perspective, may reasonably be expected from a higher education Associate Degree, Bachelor's or Master's programme.

Meets the standard
The programme meets the generic quality standard.

Partially meets the standard
The programme meets the generic quality standard to a significant extent, but improvements are required in order to fully meet the standard.

Does not meet the standard
The programme does not meet the generic quality standard.

The panel used the following definitions for the assessment of the programme as a whole:

Positive
The programme meets all the standards.

Conditionally positive
The programme meets standard 1 and partially meets a maximum of two standards, with the imposition of conditions being recommended by the panel.

Negative
In the following situations:
- The programme fails to meet one or more standards;
- The programme partially meets standard 1;
- The programme partially meets one or two standards, without the imposition of conditions being recommended by the panel;
- The programme partially meets three or more standards.

SUMMARY JUDGEMENT

As a separate master's programme in Astronomy, the programme occupies a special position within the field and allows students to both broaden and deepen their knowledge in astronomy. It convincingly profiles itself as a research-oriented programme with a strong focus on transferable skills and embeds students in the excellent research environment of the Leidse Sterrewacht. The specialisations in data science and instrumentation are good additions to the programme, to prepare for either an academic or a professional career. The intended learning outcomes are aligned with the expectations of the academic and professional field through a European domain-specific reference framework, and are fitting for an academic master's programme in terms of level and orientation.

The teaching-learning environment of the programme facilitates students achieving the intended learning outcomes. The specialisations offer students the opportunity to deepen their knowledge and skills in astronomy and engage in research at the frontiers of the field. Students are offered a large amount of flexibility and choice in composing their own curriculum. The programme provides students with close guidance and coaching throughout their curriculum, assisting them to compose a feasible and coherent programme. The panel recommends that the programme explore possibilities to connect better with the society-oriented specialisations, in order to provide students who choose them with a more coherent programme.

The fact that students conduct their research projects parallel to their courses, and as a result are embedded in the research groups throughout the entire programme, offers them hands-on experience in research, including associated skills such as writing and communicating, fitting the goals of the programme. The panel is positive about the 'double thesis' philosophy of the programme, which it considers a good learning experience for students. The use of English as the language of instruction fits the international character of the field. The teachers of the programme are experts in their field and very well equipped to help students become acquainted with research.

The master's programme Astronomy has an adequate assessment system that assesses students on all intended learning outcomes. The assessment methods are varied and fit the programme's goals. A quality assurance system with a peer-review principle applied to all exam questions and the assessment of the master's project enhances the validity and transparency of student assessment. The panel advises better monitoring of the compliance with completing the assessment forms and designing separate rubrics for the bachelor's and master's projects. The Board of Examiners adequately fulfils its role in the quality assurance of assessment, but could take a more proactive and normative stance towards the programme management. The panel recommends investigating more involvement in the assessment of the society-oriented specialisations, for instance by providing second examiners for projects.

The panel concludes that the final projects of the master's programme Astronomy are of a good quality, and convincingly show that the intended learning outcomes are achieved. The individual embedding of students in a research group and their training by active researchers was clearly reflected in the high quality of the work, which showed good academic and research skills. This is further demonstrated by the high number of students who start a PhD and the excellent job perspectives of all students, both in academia and in R&D or IT.

The panel assesses the standards from the *Assessment framework for limited programme assessments* in the following way:

Master's programme Astronomy

Standard 1: Intended learning outcomes	meets the standard
Standard 2: Teaching-learning environment	meets the standard
Standard 3: Student assessment	meets the standard
Standard 4: Achieved learning outcomes	meets the standard
General conclusion	positive

The chair of the panel, prof. dr. Reinder Coehoorn, and the secretary, Peter Hildering MSc, hereby declare that all panel members have studied this report and that they agree with the judgements laid down in the report. They confirm that the assessment has been conducted in accordance with the demands relating to independence.

Date: 23 september 2019

DESCRIPTION OF THE STANDARDS FROM THE ASSESSMENT FRAMEWORK FOR LIMITED FRAMEWORK ASSESSMENTS

Standard 1: Intended learning outcomes
The intended learning outcomes tie in with the level and orientation of the programme; they are geared to the expectations of the professional field, the discipline, and international requirements.

Findings

The master's programme Astronomy is organised, alongside the bachelor's programme Astronomy, by the Leidse Sterrewacht [observatory], which is part of the Faculteit Wiskunde en Natuurwetenschappen (FWN; Faculty of Science) of Leiden University. The programme offers four research-oriented specialisations: Astronomy Research, Cosmology, Data Science and Instrumentation. The Leidse Sterrewacht has a close cooperation with the Leiden Instituut voor Onderzoek in de Natuurkunde (LION; Leiden Institute of Physics), the FWN institute that offers the related bachelor's and master's programme Physics.

Additionally, the programme offers students the opportunity to participate in one of three society-oriented specialisations: Science-Based Business (SBB), Science Communication and Society (SCS) and Education (EDU). These are faculty-wide specialisations in which students from all the faculty's master's programmes can participate.

Vision and profile
The master's programme Astronomy distinguishes itself both nationally and internationally by positioning itself as a separate master's programme instead of a specialisation within a Physics and Astronomy master's programme, which is more usual. Together with the largest staff and student numbers in Astronomy in the Netherlands, this allows the programme to offer a breadth of research topics and specialisations for students to choose from.

The programme aims to educate its students to be competitive in international research or in the broader knowledge-based job market. Compared to the bachelor's programme, this requires deepening of knowledge and skills and active knowledge of state-of-the-art research in specific areas of astronomy, as well as professional competences such as learning ability and independence. In recent years, the master's programme has developed itself in the direction of computer science for astronomy, adding specialisations in Astronomy and Instrumentation and Astronomy and Data Science to its portfolio. This not only aligns with developments within the field of astronomy, it also gives students an additional outlook for an applied research job due to the high demand for graduates with computer science skills.

The programme views itself as research-oriented, with a strong emphasis on the development of transferable skills applicable to careers both inside and outside academia. Within the research specialisations, the programme offers a high degree of flexibility, allowing students to shape their own curriculum based on their own interests. Students are typically embedded within a research group for their research assignments, usually at the Leidse Sterrewacht and in some cases at an external group. As a result, they are trained on the job by experts in the field.

The panel recognises the vision and profile as described by the programme. The programme has a strong focus on research and transferable skills, and offers ample opportunities for tailoring to the interests of the individual students in the context of an excellent research environment. The panel approves the new specialisations on data science and instrumentation, and thinks that they are attractive for students pursuing an academic career as well as those interested in an applied science job. It values the position of the programme as a separate master's programme and thinks that this gives students an excellent position to both broaden and deepen their knowledge in astronomy.

Intended learning outcomes
The programme has aligned its intended learning outcomes with the domain-specific reference framework Physics (Appendix 1). This framework, which is used by all Physics and Astronomy programmes in the Netherlands, is the international standard for programmes within the field and was developed in a joint process at the European level (Tuning Physics) to align the Physics and Astronomy programmes at an international level. These intended learning outcomes use the Dublin descriptors to describe knowledge, insights and skills that each master's student should achieve in either Physics or Astronomy, regardless of his or her specialisation. Additionally, the programme uses eight final qualifications derived from the faculty-wide FWN learning outcomes, which the faculty aims to realise for all of its master's students. The programme translated them into domain-specific knowledge, insights and skills that each graduate of the master's programme Astronomy should have achieved. Finally, each of the specialisations has an additional qualification.

The panel studied these domain-specific and faculty-wide intended learning outcomes and concluded that they provide an appropriate and insightful overview of the target exit qualifications for students of the programme. The academic orientation and master's level are clearly visible through the link to the Dublin descriptors. The panel is positive about the alignment of the Physics and Astronomy programmes at a European level and thinks that this advances the general recognition by both the academic and the professional field of the knowledge, insights and skills acquired by the students.

Considerations

As a separate master's programme in Astronomy, the programme occupies a special position within the field and allows students to both broaden and deepen their knowledge in astronomy. It convincingly profiles itself as a research-oriented programme with a strong focus on transferable skills and embeds students in the excellent research environment of the Leidse Sterrewacht. The specialisations in data science and instrumentations are good additions to the programme, to prepare for either an academic or a professional career. The intended learning outcomes are aligned with the expectations of the academic and professional field through a European domain-specific reference framework, and are fitting for an academic master's programme in terms of level and orientation.

Conclusion
Master's programme Astronomy: the panel assesses Standard 1 as 'meets the standard'.

Standard 2: Teaching-learning environment
The curriculum, the teaching-learning environment and the quality of the teaching staff enable the incoming students to achieve the intended learning outcomes.

Findings

Curriculum
The master's programme Astronomy offers a flexible curriculum in which students can compose their personal schedule from a series of courses on offer. These are arranged into four specialisations: Astronomy Research, Cosmology, Instrumentation and Data Science. The Astronomy Research specialisation is the research track covering the topics studied at the Leidse Sterrewacht, while Cosmology, Instrumentation and Data Science are specialisations with a specific focus. The Cosmology specialisation is focused on astrophysics and is offered in close collaboration with the LION Institute of Physics. It has a significant overlap with the similarly named specialisation in the master's programme Physics, although it differs as two mandatory courses are more astronomy rather than physics oriented. The Instrumentation and Data Science specialisations are more focused on a career outside academia and educate students in astronomical hardware development or big data. The latter is offered in collaboration with the LIACS Computer Science Department of Leiden University.

Students choose one of these specialisations and compose a personal curriculum around it. This personal schedule follows a basic structure with a number of key points. Given the intended learning outcomes in terms of research skills, experience and insight, hands-on research is a key element. The programme requires all students to spend 60 EC on research projects throughout the curriculum. These are split in two 30 EC projects, to be carried out on two different topics. By having students do two research projects, the programme aims to introduce them to a larger diversity in research and training offered by different researchers from different groups. The other 60 EC are spent on coursework in astronomy, or courses from the master's programmes Physics, Mathematics or Computer Science. Each specialisation has a number of core courses and specialisation-specific electives. Students can also choose general astronomy courses and instrumentation-related courses. During the programme, students work on courses and the research projects in parallel.

At the start of their studies, students compose a personal study plan with the study advisor, specifying the courses and research projects offered by the research group(s) in which he or she will be embedded during the master's programme. The study advisor ensures the coherence and feasibility of the individual curriculum. The connection of this curriculum to the intended learning outcomes of the programme is covered through the mandatory courses, the research projects and the fact that students are embedded in a research environment.

The panel studied the curriculum of the programme and the content of the specialisations and finds that this offers students the opportunity to deepen their knowledge and skills in astronomy and engage themselves in research at the frontiers of astronomy. It values the extent of flexibility and choice offered to the students to compose their own curriculum, in terms of content as well as academic or professional orientation. The fact that students conduct their research projects parallel to their courses, and as a result are embedded in the research groups throughout the entire programme, offers them hands-on experience in research, including associated skills such as writing and communicating, fitting the goals of the programme. The panel is positive about the 'double thesis' philosophy of the programme. It thinks that experiencing a diversity in topics and approaches is a good learning experience for students.

Society-oriented specialisations
Students who participate in one of three society-oriented specialisations follow an adapted curriculum. They carry out 30 EC of astronomy research projects in the first year, alongside 30 EC of astronomy courses. The second part of the curriculum is fully dedicated to courses in Science-Based Business (SBB), Science Communication and Society (SCS) or Education (EDU). These are faculty-wide specialisations in which students from all the faculty's master's programmes can participate. The research project counts as the thesis for this programme, while the specialisation is completed by either an internship (SBB, SCS) or teaching practice (EDU). The specialisations typically attract only a very small number of Astronomy students per year (1 or 2).

The panel studied the way in which the society-oriented specialisations are embedded in the master's programme Astronomy. It read a number of internship reports for the SBB specialisation and spoke to the SBB programme director. It deduced that there is hardly any connection between the science part and the business-oriented part of the programme: astronomy students follow the same curriculum as biology or chemistry students enrolled in the specialisation. The specialisations are organised by a separate department within the faculty, to which all education within the specialisations is mandated. The SBB internship reports paint the same picture: students do not seem encouraged to connect their science-based business skills and knowledge with their science background. The panel thinks that this is a missed opportunity, as there are many possible connections between astronomy and science-based business that would make the two curricula more than the sum of its parts. It recommends that the programme explore possibilities to connect better with the society-oriented specialisations, in order to provide students that choose these specialisations with a more coherent programme.

Didactics
The master's programme mostly consists of small-scale courses that are typically attended by 10-20 students. Most courses are taught as lecture series based on the research literature, to which students contribute with mini-project presentations. Due to the small number of students, these courses are usually very interactive. According to the programme, the main didactical approach is the embedding of students within the research institute and supervision by experienced researchers. The programme aims for its students to learn through a master-apprentice approach and by experiencing a high-quality research environment.

Students indicated to the panel that they very much enjoy this experience, and that they feel treated as an equal in the research groups. They have the opportunity to join colloquia, meet international visitors and work on the frontier of the field. They utilise the research group's facilities and have use of a desk with PC, lab space and access to common facilities. The panel is positive about the didactics of the programme and finds that a master-apprentice approach in a vibrant research environment is fitting for a research-oriented master's programme focusing on research skills.

Language and internationalisation
The teaching language of the programme is English, which is the common language for research in the natural sciences and therefore essential for a research-oriented programme. As active researchers in the field, the teaching staff has sufficiently mastered the English language. The panel fully supports the use of English in this master's programme and thinks that this is the obvious choice given its goals.

The programme aims for an international classroom within the programme in order to reflect the international character of the field. Approximately half of the current student population is from outside the Netherlands, most of them being non-European (USA, China, India). A major part of the teaching staff is also not Dutch, which adds to the international character of the programme. The programme is satisfied with the percentage of international students and considers a 50-50 balance as the maximum level. It offers three scholarships for very strong non-EU students, which includes a stipend and a waiver of the tuition fee to the national level. For students with a non-Dutch bachelor's degree applying to the programme, a Board of Admissions evaluates the degree obtained and the equivalence of the degree to a Leiden bachelor's degree in Astronomy to decide whether it provides enough foundation for the candidate to complete the master's programme. If there are deficiencies, students can be asked to eliminate them in a pre-master's programme with a maximum of 60 EC. A specific pre-master's programme has been designed for students with a bachelor's degree in Aerospace Technology due to the frequency of applications from students with that background.

The programme facilitates international students by helping them find housing, which is currently a major challenge in the Leiden region, and invests in a quick embedding in the institute through social events and by offering a buddy system. The latter pairs international students with a PhD or older master's student with a similar cultural background who can help them find their way. The international students whom the panel spoke to felt welcomed within the programme and were pleased with the accessibility of their teachers and the small-scale character of the programme. The panel thinks that the level of internationalisation fits the goals of the programme and praises the programme for its attention to the integration of international students.

Feasibility
Since the majority of the programme is customised, students have a large amount of control over the structure of their personal curriculum. The study advisor plays a major role in helping them construct a feasible curriculum. At the start of their studies, the study advisor helps each student set up a study plan, detailing the courses and research projects the student intends to take. Subsequently, the study advisor monitors the student's progress and advises on and approves modifications of the study plan if necessary. During their research projects, students are monitored by their supervisor, who is a researcher within the institute they are embedded in. This is usually a close relationship in which they are actively coached throughout their project in frequent meetings.

Students are motivated to complete their research projects within the set time and are assessed on their time management skills as part of the project assessment. As a result, most students finish their programme on time, with an average graduation time between 2.2 and 2.5 years.

Close guidance of students is a key characteristic of the programme. In the last couple of years, the programme invested in the professionalisation of education support through the Education Office Astronomy (EOA). This Office has 4.8 fte support specifically for the bachelor's and master's programme Astronomy, which focuses on support of students, communication, secretarial support and internationalisation. The panel praises the personal attention and guidance given to students by the programme and the help they receive in constructing their personal curriculum, and considers this a very good service to students. Students are generally satisfied with the feasibility of their curriculum and praise the guidance they receive from their supervisors and the programme in general. The panel appreciates the attention paid to time management, which helps the students to complete their research projects in a timely manner.

Teaching staff
The teaching staff of the programme is associated with the Leidse Sterrewacht, or in some cases with one of the other institutes at FWN, such as the LION Institute of Physics or the LIACS Institute of Advanced Computer Science for the data science specialisation. All of them have a PhD and are employed in permanent or tenure-track positions. Obtaining a Basic Qualification in Teaching certificate (BKO) has been a prerequisite for every new teacher since 2008, and 90% of the programme's teachers currently have one. The programme and faculty organise at least four thematic meetings on education each year. Each teacher typically teaches 1-2 courses per year, and changes courses every three to five years. The programme put this mechanism in place to prevent courses from becoming stale and keep its teachers challenged. The teaching staff supports this philosophy and feel challenged to keep their courses fresh. All teachers in the master's programme are active researchers and thus are very well equipped to teach students as apprentices.

Students are very enthusiastic about their teachers and feel incorporated in a small-scale programme with very approachable staff. They feel that their teachers put a lot of effort into teaching and are always prepared to make an effort to help them. The panel agrees with the students. As active researchers in the field in an excellent research institute, the teaching staff is very well equipped to guide students to develop their research skills. It also deems the four-yearly changes in teaching staff within the courses a good measure to keep the courses fresh and up-to-date. According to the panel, the teaching staff's support of this mechanism underlines the value that the teaching staff attaches to education.

Considerations

The teaching-learning environment of the programme facilitates students achieving the intended learning outcomes. The specialisations offer students the opportunity to deepen their knowledge and skills in astronomy and engage in research at the frontiers of the field. Students are offered a large amount of flexibility and choice in composing their own curriculum. The programme provides students with close guidance and coaching throughout their curriculum, assisting them to compose a feasible and coherent programme. The panel recommends that the programme explore possibilities to connect better with the society-oriented specialisations, in order to provide students who choose them with a more coherent programme.

The fact that students conduct their research projects parallel to their courses, and as a result are embedded in the research groups throughout the entire programme, offers them hands-on experience in research, including associated skills such as writing and communicating, fitting the goals of the programme. The panel is positive about the 'double thesis' philosophy of the programme, which it considers a good learning experience for students. The use of English as the language of instruction fits the international character of the field. The teachers of the programme are experts in their field and very well equipped to help students become acquainted with research.

Conclusion
Master's programme Astronomy: the panel assesses Standard 2 as 'meets the standard'.

Standard 3: Student assessment
The programme has an adequate system of student assessment in place.

Findings

Assessment system
The programme uses various formats to assess the knowledge, understanding and skills of students. They include written exams with open questions, written reports, oral presentations, essays and demonstration of particular skills, such as programming. The particular form of assessment depends on the nature of the course and can be defined by the teacher as long as it is explicitly made clear beforehand what students can expect concerning the nature, form, depth, length and content of the assessment. The quality of exam questions and answers is checked before the examination by a second reader in terms of clarity, length, level and coverage of the course materials. If necessary, a teaching assistant does a 'test run' of the exam to check whether its length and difficulty need adjusting. The assessment methods are designed to collectively assess all essential skills, such as presenting, writing and working independently.

The panel studied the assessment system of the programme, an overview of the assessment methods and criteria per course, and some examples of exams used within the programme. It is positive about the variety of assessment methods and the attention paid to the assessment of various research skills within the programme, which fits the programme's goals. The independent check of all exam questions by the second reader is a good method to increase the validity of the exams.

Assessment research projects
Students conclude the programme with two research projects. During these projects, they are embedded within one of the Sterrewacht research groups. They select their own topic in consultation with their supervisor. Additionally, they require consent from the study advisor, who checks whether the content and methodology of the project align with the programme's intended learning outcomes and the student's individual curriculum. The final grade is determined by two independent examiners: the daily supervisor and an independent second examiner from another research group. The assessment focuses on three aspects: research, thesis and oral presentation. The two examiners decide collectively on a grade on all three aspects, and substantiate and register this on an assessment form. If the two examiners cannot agree on a grade, the grade will be the average of their grades. Every thesis is checked for plagiarism using Turnitin software and is stored online in a thesis archive. The assessment form was redesigned in 2018, and consists of seven criteria that assessors can grade using a rubric. This redesign was aimed at improving the uniformity of the assessments.

The panel thinks that the assessment procedure for research projects is adequate. The independent second reader increases the validity of the grading. The panel studied a number of old and new assessment forms as part of the thesis check conducted prior to the site visit. It concluded that the current assessment form makes a better distinction between research, thesis and oral presentation, and provides better insight into the composition of the final grade. It notes, however, that a number of assessment forms could be improved in terms of transparency, as they lacked or partially lacked qualitative feedback. This also affects the students involved, as they do not have a written motivation of the feedback on their work. The programme management and Board of Examiners stated that this is not intentional, and that it is standing policy that all forms should contain sufficient written feedback. The panel advises the programme to enforce this.

The panel noted that the programme uses the same assessment form as the bachelor's programme Astronomy. The programme commented that examiners are responsible for grading master's

students on stricter criteria, but also admitted that it is not fully satisfied with this situation and would like to introduce two different forms. The panel encourages the programme to carry out these plans. The bachelor's and master's projects have separate goals and should therefore not be assessed by the same criteria. It advises the programme to differentiate between the two programmes and to change the assessment form accordingly.

Board of Examiners
The master's programme Astronomy shares a Board of Examiners with the bachelor's programme Astronomy. This Board has four members from the programmes and one external member. The Board appoints the programme's examiners and monitors the quality of assessment within the programme. It performs systematic checks of the exams within the programme in terms of clarity, completeness and level of difficulty. It checks all exams and the accompanying solutions and grading key twice a year. It conducts these checks itself, assisted if necessary by additional experts. It has not found any major shortcomings in the programme's assessment in the past years. A sample of master's projects is checked annually for adequate grading and thesis quality, as well as the correct use of the assessment form. Recently, the Board noted that the grades in the programme were quite high, which has led to the introduction of the rubric mentioned above to harmonise the grading. For the society-oriented specialisations, the faculty has mandated two dedicated Boards of Examiners: one for the educational specialisation and one for the business and communication specialisations. The Board for the specialisations takes care of the quality of assessment within these specialisations. Formally, the Astronomy Board of Examiners has mandated its responsibility for these three variants to these specialisation-specific Boards. These Boards report back annually to the Astronomy Board of Examiners, or whenever issues require a direct response.

The panel spoke with the Board of Examiners, including one member of the Communication and Business mandated Board, and studied a number of its annual reports. It judged that the Board adequately fulfils its role in the quality assurance of assessment within the programme, although it could be more proactive. For instance, the Board did note that the compliance for completing the assessment forms could be better, and that the programme would benefit from separate forms for assessment of the bachelor's and master's project, but did not closely monitor the follow-up of these suggestions. The panel recommends that the Board take a more proactive and normative stance towards the programme management.

The panel noted that the assessment within the society-oriented specialisations is fully mandated to the related Boards of Examiners. In order to improve the coherence between these specialisations and the astronomy-oriented side of the programme (discussed under Standard 2), it recommends investigating whether there could be more involvement in the assessment of the society-oriented specialisations. The programme could, for instance, consider providing second examiners for the projects within the specialisations to monitor more closely the performance of their students within these specialisations.

Considerations

The master's programme Astronomy has an adequate assessment system that assesses students on all intended learning outcomes. The assessment methods are varied and fit the programme's goals. A quality assurance system with a peer-review principle applied to all exam questions and the assessment of the master's project enhances the validity and transparency of student assessment. The panel advises better monitoring of the compliance with completing the assessment forms and designing separate rubrics for the bachelor's and master's projects. The Board of Examiners adequately fulfils its role in the quality assurance of assessment, but could take a more proactive and normative stance towards the programme management. The panel recommends investigating more involvement in the assessment of the society-oriented specialisations, for instance by providing second examiners for projects.

Conclusion
Master's programme Astronomy the panel assesses Standard 3 as 'meets the standard'.

Standard 4: Achieved learning outcomes
The programme demonstrates that the intended learning outcomes are achieved.

Findings

Final projects
Students conclude the programme with two research projects. During these projects, they are embedded within one of Sterrewacht's research groups. Before the site visit, the panel studied 12 master's projects (see Working Method), divided over the four specialisations. This selection also included two astronomy projects of students who chose a society-oriented specialisation. The panel was very positive about the quality of the master's theses. The individual embedding of students in a research group and their training by active researchers was clearly reflected in the high quality of the work, which showed good academic and research skills. Students who did two research projects were able to demonstrate their research skills in two different settings, which was highly valued by the panel. The final projects by students who chose a society-oriented specialisation were deemed adequate by the panel to cover the intended learning outcomes of the programme.

Performance of alumni
A recent survey conducted by the programme among the last three cohorts revealed that all alumni find a job, most of them within a few months. A high number of the programme's alumni (50%) go on to a PhD, half of them in Leiden and half of them elsewhere. The remaining 50% start their career outside academia, where R&D and IT & Data Science are the leading choices. According to the panel, the high number of alumni continuing in research and academia reflects the successful realisation by students of the programme's goals and intended learning outcomes, which are focused on research and academic skills. The students continuing in R&D and IT showed that the programme's efforts to present career opportunities outside academia through the Instrumentation and Data Science tracks pay off. The panel congratulates the programme on its success in this respect, as well as the excellent job prospects of its alumni.

Considerations
The panel concludes that the final projects of the master's programme Astronomy are of a good quality, and convincingly show that the intended learning outcomes are achieved. The individual embedding of students in a research group and their training by active researchers was clearly reflected in the high quality of the work, which showed good academic and research skills. This is further demonstrated by the high number of students who start a PhD and the excellent job perspectives of all students, both in academia and in R&D or IT.

Conclusion
Master's programme Astronomy: the panel assesses Standard 4 as 'meets the standard'.

GENERAL CONCLUSION

The panel assesses all standards of the NVAO's Framework for a limited programme assessment 2018 for the master's programme Astronomy as 'meets the standard'. According to the decision rules of the framework, the panel assesses the master's programme Astronomy as positive.

Conclusion
The panel assesses the *master's programme Astronomy* as 'positive.

APPENDICES

APPENDIX 1: DOMAIN-SPECIFIC FRAMEWORK OF REFERENCE

Introduction
The goal of a university programme is to prepare students for an independent practice of the profession of the relevant discipline, and to give them the ability to apply the knowledge and skills they have acquired. Dutch university programmes in the domain of (applied) physics and astronomy are required to reach a level which allows the graduate to be competitive in the international research or in the job market, in particular with respect to countries which have a high profile in these areas. The domain specific reference frame is meant to be a gauge for reaching this goal.

The framework is based on that used in the Teaching Programme Assessment (Onderwijsvisitatie) of 2013. This in its turn was derived from the qualifications as formulated in the document 'Reference points for the design and delivery of degree programmes in physics', which was a product of the so-called Tuning Project63[1] and, to a lesser extent, the document 'A European Specification for Physics Master Studies' of the European Physical Society (2009). The 2013 framework has been modified and updated in three ways: (1) the programme descriptors are now divided over the usual five Dublin indicators, instead of over the original three categories: cognitive competences, practical skills, and generic competences, (2) several competences have been rephrased, (3) the competence 'Estimation skills' has been added.

The descriptors for the programmes have been formulated in terms of competences acquired by the graduating student, which leads to specific requirements for the curriculum. Programmes with the same name at different (Dutch) universities will in general not be identical. Different specialisations in the research staff or focus on particular subjects leads to differences in the eligible part of the programmes, and there is a structural difference between (the goals of) general universities and universities of technology. As a consequence, there are different ways to comply with the requirements of the reference frame. Essential is that the local choices for, and focus of the programme fit the internationally accepted standards.

Programme descriptors
The descriptors for the Bachelor's degree programmes in Physics, Applied Physics, and Astronomy are divided over the five Dublin descriptors, where the highest or most relevant descriptor is used for this division. The number in the second column is the 'Rating of importance' at the Bachelor level mentioned in the Tuning Physics document. The competence 'Estimation skills' and the related competence 'Problem solving skills' are combined (ratings 2 and 9). The three colors indicate the type of competence: light color = core curriculum, medium color = familiarity with physics research, dark color = general skills.

[1] In May 2018 a new version of the Tuning document was published, as output of the CALOHEE project (https://www.calohee.eu/). In this document, a different structure of competences is proposed (nine 'disciplines', each divided into 'knowledge', 'skills' and 'wider competences'). The compilers of the present framework have decided to follow the simpler, yet elegant structure of the Tuning 2008 document. Where relevant, aspects of the Tuning (2018) have been incorporated.

(A) Knowledge and understanding

	Rating of importance	Specific competence	Description. On completion of the degree course, the student should
A1	5	Knowledge and understanding of physics	have a good understanding of the important physical theories (logical and mathematical structure, experimental support, physical phenomena described).
A2	14	Understanding of the physics culture	be familiar with the most important areas of physics and with the common approaches, which span many areas in physics.
A3	8	Frontier research (MSc only)	have a good knowledge of the state of the art in (at least) one of the presently active topics in physics research.

(B) Applying knowledge and understanding

		Specific competence	Description. On completion of the degree course, the student should
B1	2, 9	Problem solving skills, Estimation skills	be able to frame, analyse and break down a problem in phases defining a suitable algorithmic procedure; be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems.

B2	1	Modelling skills	be able to identify the essentials of a process/situation and to set up a working model of the same; be able to perform the required approximations; *i.e.* critically think about how to construct physical models.
B3	7	Mathematical skills	be able to understand and master the use of the most commonly used mathematical and numerical methods.
B4	10	Experimental skills	have become familiar with most important experimental methods and be able to perform experiments independently, as well as to describe, analyse and critically evaluate experimental data; and to be able to scientifically report the findings.
B5		Computer skills	be able to use appropriate software, programming language, computational tools and methods in physical and mathematical investigations.
B6	6	Familiarity with basic and applied research	acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, *e.g.* engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.

(C) Judgement

C1	13	Human / professional skills	be able to develop a personal sense of responsibility; be able to gain professional flexibility through the wide spectrum of scientific techniques offered in the curriculum; be able to organize the personal learning process, evaluate personal work, consult experts for information (*e.g.* about career opportunities) and support when

			appropriate; have had the opportunity to take courses that prepare for teaching physics at secondary school, as well as the opportunity to gain in-depth interdisciplinary skills.
C2	18	Absolute standards	have become familiar with highly regarded research in the field, thus developing an awareness of the highest standards.
C3	17	Ethical awareness (relevant for physics)	be able to understand the socially related problems related to the profession, and to comprehend the ethical characteristics of research and of the professional activity in physics and its responsibility to society; be able to conduct processes of decision making and inspect the consequences of actions taking into account principles, norms, values and standards both from a personal and a professional standpoint.
C4	12	Management skills (MSc only)	be able to work with a high degree of autonomy, even accepting responsibility in (project) planning, and in the managing of structures.

(D) Communication

D1	11	Communication skills	be able to listen carefully and to present difficult ideas and complex information in a clear and concise manner to a professional as well as to lay audiences; be able to work in a multidisciplinary or in an interdisciplinary team.
D2	16	Language skills	be able to read, speak, and write in technical English.

(E) Learning

E1	3	Literature search	be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development.
E2	4	Learning ability	be able to enter new fields through independent study; have developed those learning skills that are necessary for them to continue to undertake further study with a high degree of autonomy (lifelong learning).
E3	15	Updating skills (MSc only)	enjoy the facility to remain informed of new developments and methods, and be able to provide professional advice on their possible impact or range of applications.

APPENDIX 2: INTENDED LEARNING OUTCOMES

Graduates of the programme have attained the following learning outcomes, listed according to the Dublin descriptors:

a. theoretical and/or practical skills in more than one specialist area of the discipline such that they can carry out research under overall supervision;
b. the ability to make an independent analysis of scientific problems, analysis of relevant specialist literature, formulate verifiable hypotheses, and set up and carry out research and critical reflection on one's own research and that of others;
c. the ability to interrelate and integrate various areas of the discipline;
d. the ability to present clearly, verbally as well as in writing, one's own research results, and the ability to communicate with colleagues and to present their research results as a contribution to a congress or as (part of) a scientific publication;
e. sufficient understanding of the social role of the natural sciences to be able to reflect upon them and in part consequently to come to an ethically sound attitude and corresponding execution of one's professional duties;
f. have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous.

For the master specialisations Business Studies, Science Communication and Society and Education, the following additional achievement levels apply:

Business Studies specialisation:

a. insight in managerial issues related to knowledge-intensive businesses and basic theoretical skills in business disciplines most relevant to working in these businesses;
b. the ability to make a plan for a new business or an innovation project;
c. experience with performing business activities in an existing company or organisation or directed towards technology-based business creation.

Science Communication and Society specialisation:

a. knowledge of and skills in science communication theory and methods ;
b. experience in science communication practice;
c. knowledge of ethical, historical and social aspects in the area of the natural sciences.

Education specialisation:

- all qualifications necessary for teaching all years of secondary education and technical and vocational training (students from 12 to 18 years old).

Depending on the specialisation chosen, the following additional learning outcomes apply:

Specialisation "Astronomy Research":

- the graduate has state-of-the-art knowledge of two different areas of astronomy.

Specialisation "Astronomy and Cosmology":

- the graduate has up-to-date knowledge and understanding of the field of cosmology, including both theoretical and observational aspects, and state-of-the-art knowledge of at least one area in this field.

Specialisation "Astronomy and Instrumentation":

- the graduate has up-to-date knowledge in the field of astronomical instrumentation, and state-of-the-art knowledge and practical skills in at least one area in this field.

Specialisation "Astronomy and Data Science":

- the graduate has up-to-date in knowledge of the field of data science and computational techniques applied to the field of astronomy, and state-of-the-art knowledge and practical skills in at least one area of this field.

Specialisation "Astronomy and Business Studies":

- the graduate has knowledge of the basic analytical frameworks, and the skills to analyse business-related problems and to contribute to managerial decision making, either within the context of established knowledge-intensive organisations or within the context of new technology ventures.

This specialisation separates into a "Management" track and a "New Technology Ventures" track, each with its own specific learning outcomes as specified in the OER (Appendix 1):

Specialisation "Astronomy and Science Communication & Society":

- the graduate has knowledge and experience in science communication using modern technology.

Specialisation "Astronomy and Education":

- the graduate has the required qualifications for teaching physics at all levels of secondary education and technical and vocational training ("eerstegraads lesbevoegdheid").

APPENDIX 3: OVERVIEW OF THE CURRICULUM

Vak	EC
Astronomy Master's Research Projects	
First Research Project Astronomy	30
Master's Research Project Astronomy 2	30
Astronomy Core Courses	
Origin and Evolution of the Universe	6
Stellar Structure and Evolution	6
Large Scale Structure and Galaxy Formation	6
General Astronomy Courses	
Computational Astrophysics	6
Instrumentation-related Astronomy Courses	
Astronomical Telescopes and Instruments	6
Radio Astronomy	6
Detection of Light a	3
Detection of Light a + b	6
Specialist Astronomy Courses	
Astronomical Spectroscopy	3
High-energy Astrophysics	3
Modern Astrostatistics	3
Numerical Recipes in Astrophysics	6
Inter-faculty Electives	
Science and the public: contemporary and historical perspectives	6

APPENDIX 4: PROGRAMME OF THE SITE VISIT

Tuesday 23 April
09.00 – 09.15 Arrival
09.15 – 11.00 Internal panel session
11.00 – 12.00 **Interview programme management**
12.00 – 12.30 Consultation hour
12.30 – 13.30 Lunch
13.30 – 14.15 **Tour of the facilities**
14.15 – 14.30 Break
14.30 – 15.30 **Interview Students bachelor Physics + Astronomy**
15.30 – 15.45 Break
15.45 – 16.30 **Interview students master Astronomy**
16.30 – 17.15 **Interview students master Physics**
17.15 – 17.45 Internal panel session

Wednesday 24 April
09.00 – 09.30 Internal panel session
09.30 – 10.15 **Interview teaching staff Astronomy (bachelor + master)**
10.15 – 11.00 **Interview teaching staff Physics (bachelor + master)**
11.00 – 11.30 Break
11.30 – 12.15 **Interview Board of Examiners**
12.15 – 13.15 Lunch
13.15 – 14.00 **Interview programme management**
14.00 – 16.00 Internal panel session
16.00 – 16.15 **Oral report**
16.15 – 17.00 **Development dialogue**
17.15 – 17.30 Wrap up

APPENDIX 5: THESES AND DOCUMENTS STUDIED BY THE PANEL

Prior to the site visit, the panel studied 12 theses of the master's programme Astronomy. Information on the selected theses is available from QANU upon request.

During the site visit, the panel studied, among other things, the following documents (partly as hard copies, partly via the institute's electronic learning environment):

- Intended learning outcomes
- Curriculum overview
- Overview programme content (study guide, electronic learning environment and a selection of course materials)
- Selection of exam questions and answer models
- Education and Exam Regulation
- Teaching staff overview
- List of theses
- Annual reports Board of Examiners Astronomy
- Annual reports Programme Committee master Astronomy
- Minutes Programme Committee master Astronomy