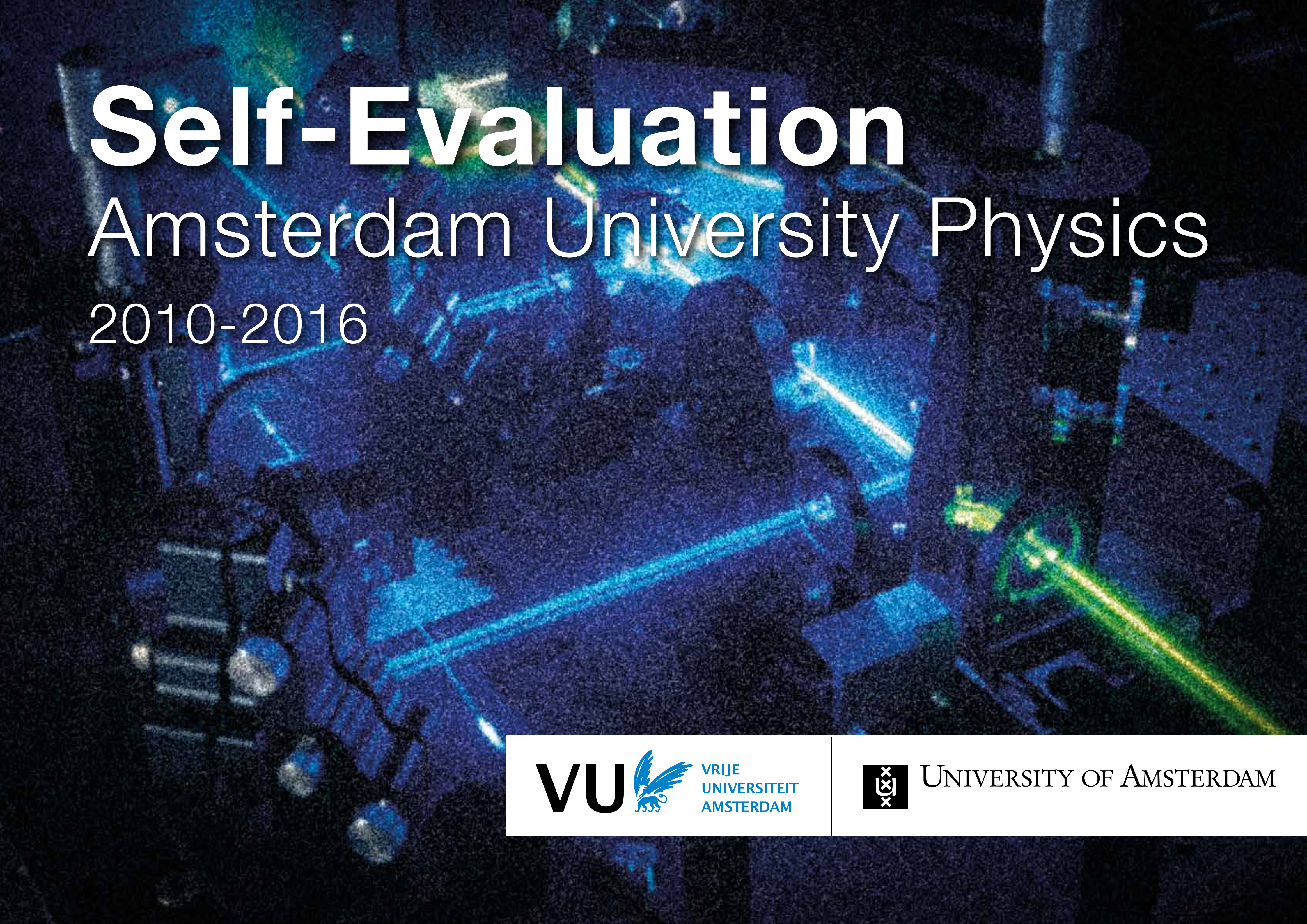
Self-Evaluation

Amsterdam University Physics

2010-2016



VU VRIJE UNIVERSITEIT AMSTERDAM

UNIVERSITY OF AMSTERDAM

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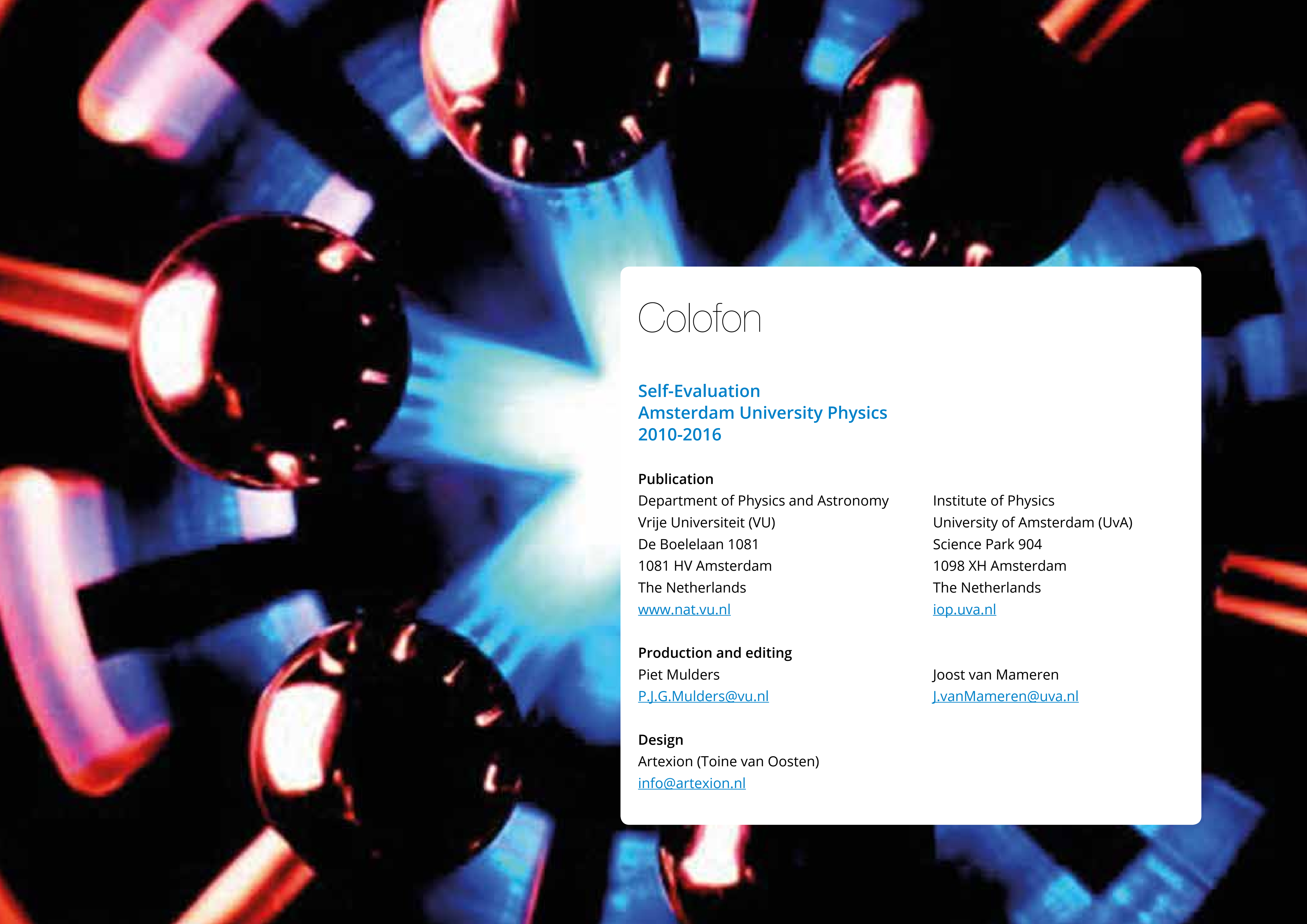

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Preamble

We proudly present the self-evaluation of the Physics Departments of the Vrije Universiteit (VU) and the University of Amsterdam (UvA). This document contains the reflection on the four research units that participate in the evaluation over the period 2010 - 2016. The research evaluation is organised under the auspices of the boards of the Universities. The procedures for this evaluation are carried out as outlined in the Standard Evaluation Protocol (SEP) 2015-2021.

The four research units to be evaluated - one of them involving researchers from both universities - have been carefully chosen based on their intrinsic coherence in research topics, requirements on infrastructure, location and international scope. The research units do not coincide with the organisational structure of the VU and UvA departments. To avoid unnecessary repetition, we have chosen to describe several general aspects in an introductory chapter (Chapter A), either at separate UvA or VU department-level (such as department organisation and financing, research integrity) or at joint UvA and VU level (such as PhD programme, education). This chapter also describes the developments during the evaluation period aimed at intensifying the collaboration in research and education between VU and UvA. These collaborations form the primary reason for both universities to jointly carry out the present evaluation.

After the introductory chapter (A), the description of the four research units is presented in four consecutive chapters:

B. VU Institute for Lasers, Life sciences and Biophotonics Amsterdam (VU LaserLaB);
C. UvA Van der Waals-Zeeman Institute (WZI);
D. UvA+VU Institute for High-Energy Physics (IHEF);
E. UvA Institute for Theoretical Physics Amsterdam (ITFA).

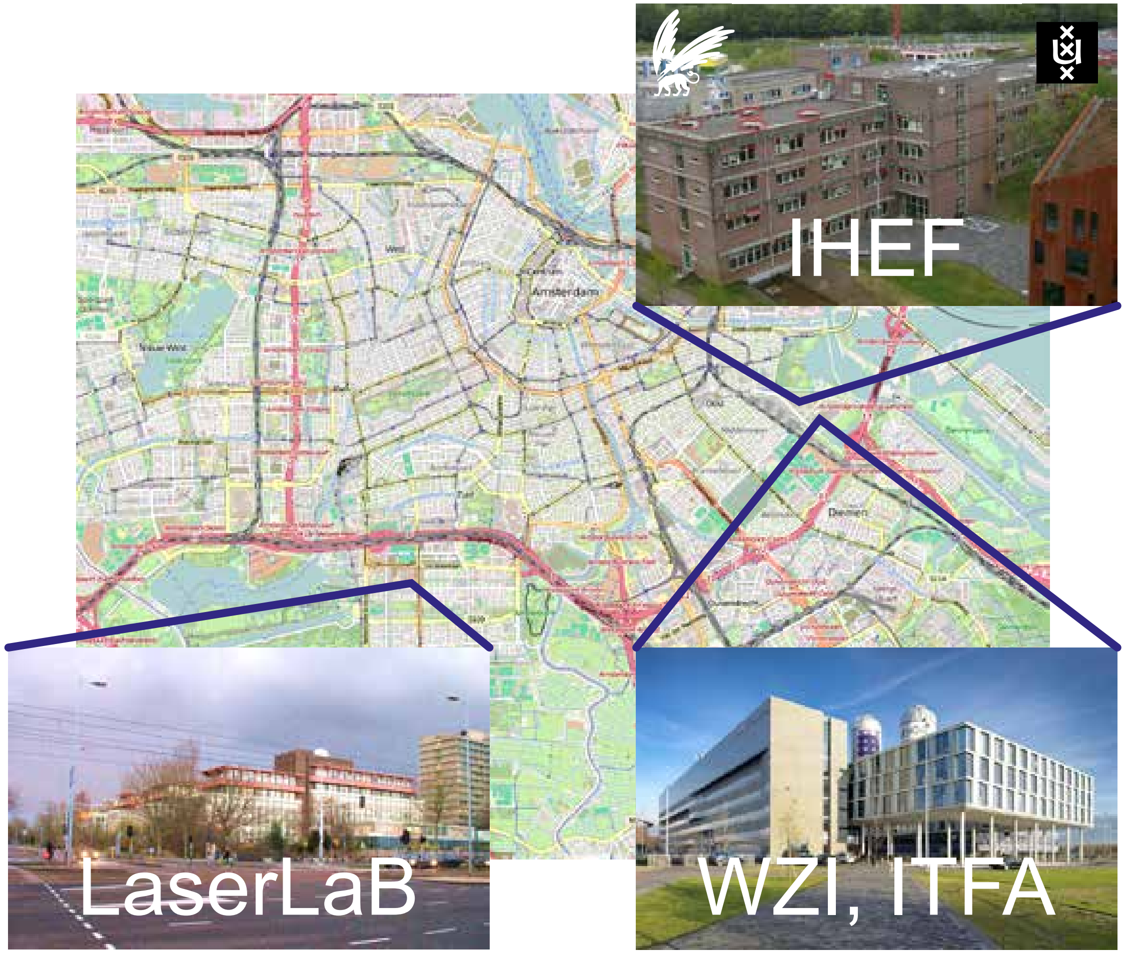
Throughout, numerous references to quantitative and/or tabulated supporting information are made, which are contained in the appendices (Chapter F).

The units described in chapter B and the VU part of chapter D together form the Department of Physics and Astronomy of the VU. The units described in chapters C, E and the UvA part of chapter D comprise the three research divisions of the UvA Institute of Physics. Their geographical positions in the city of Amsterdam are shown in the image on the next page.

We very much look forward to discussing our past and present performance and future strategy with the evaluation committee during their visit in December 2017.

Paul de Jong, director UvA Institute of Physics
Gijs Wuite, head of VU Department Physics and Astronomy

Nikhef



VU VRIJE UNIVERSITEIT AMSTERDAM

UNIVERSITY OF AMSTERDAM

A. Department-level description

A.1 VU Department of Physics and Astronomy

A.1.1 Organization, composition and financing

The VU Department of Physics and Astronomy is led by a head of department (currently Gijs Wuite). Together with the department manager (currently P.M. Erne MSc), the director of education (currently Marloes Groot) and a fourth member (currently Gerhard Raven), the head of department forms the department management team. The department decides on appointments and all matters related to finances and laboratory & office space. Final decisions on the budget are taken after consultation of the Faculty Board and the Dean of the Faculty of Science (currently Guus Schreiber). Major strategic decisions are discussed within the physics "staff convent" consisting of all tenured staff in the department, or, for some specific issues (major appointments; *cum laude* PhD awards), with all full professors at the department. Over the last years, major decisions have been made in consultation with the management team of UvA.

Over the past 10 years, the department has grown significantly thanks to very successful grant acquisition and 'Sectorplan' funds from the Dutch government. With Sectorplan funding and as a result of the focus-area policy of the VU ('speerpuntenbeleid'), the research programme of the department has been consolidated along three main profiles: **Physics of Life**, **Physics of Energy** and **Fundaments of Physics**. Each profile consists of research groups with several PIs and independent research lines. The research activities combine theoretical and experimental research. Within the Fundaments of Physics profile, the department's subatomic physics activities are embedded within the Nikhef collaboration, which brings together the expertise of five universities in the National Institute of Subatomic Physics, located in Amsterdam. These subatomic physics research activities will be described in Chapter D of this evaluation. The rest of the department's research activities are embedded in LaserLaB Amsterdam and will be described as one unit in Chapter .

Despite severe cuts in the budget allocations to universities on the national level, multiplied by equally severe budget cuts towards the science departments within VU, the Department of Physics and Astronomy has managed to grow based on external funding.

In the graph in Appendix F.3.1 we only present the development of external funding of the Department of Physics and Astronomy 2010-2016. Unfortunately, we cannot present the research-specific part of our direct funding in a meaningful way: income from research and education are typically lumped and the rules for awarding direct funding have changed several times during the evaluation period.

In the new financial arrangement of VU, the research within the department (i.e., PhD students, postdocs, equipment and running budget) is mostly financed by outside sources (FOM, NWO, EU, etc.) while the department itself provides the salaries of the scientific and support staff, the running budget for all academic staff and 'hours' for support in the electronic and mechanical machine shops. The running budget and machine shop hours are provided to the research sections according to the group size. In addition, the department has defined a "solidarity model" in which recipients of personal grants (NWO-Vidi/Vici, ERC) pay their salary or part of it from their grant. This financing model critically relies on the academic staff members obtaining external research funding.

The research in the department is well funded and has grown over the past six years covered by this self-evaluation. Funding has in particular been strong in the area of personal grants such as ERC, NWO Vici as well as many present and previous NWO-Vidi-scholars. A number of our scientists have led major national collaborative programmes in this period. Finally, our groups have been and are involved in various national or international consortia.

A.1.2 Research integrity

A.1.2.1 General reflection on research integrity and culture

The VU department of Physics and Astronomy is part of the VU Faculty of Science and thereby automatically follows the integrity policy of the university. The university policy aligns with that of the NWO, the Association of Universities in the Netherlands (VSNU) and the Royal Netherlands Academy of Arts and Sciences (KNAW). Research practices within the department thus feature the elements of scrupulousness, reliability, verifiability, impartiality and independence that are standard in this policy. It has recently been established that all VU PhD students are required to follow a course on research integrity. Part of this course is a discussion about this topic between the student and supervisor(s) on which the student has to write a report. The different research sections are responsible for the quality and integrity of the research of their own groups. In case problems arise, they are immediately escalated towards the department head and ultimately the higher management of the university. There have been no cases of scientific misconduct revealed at LaserLaB / VU department of Physics and Astronomy in the assessment period.

A.1.2.2 Data storage

The policy principles of the VU Department of Physics and Astronomy as to data storage follow the ones established by the university. Below are the main guidelines.

1. VU is strongly committed to the accessibility of research output, i.e. publications and data. They are important to the visibility, verifiability and reusability of research.
2. VU subscribes to the Netherlands Code of Conduct for Scientific Practice, drawn up by Association of Dutch Universities (VSNU). On the subject of handling research data, this code includes the following clauses:
   - Research data are collected. The statistical methods employed are pertinent to the acquired data. The selective omission of research results is reported and justified.
   - The quality of data collection, data entry, data storage and data processing is guarded closely. All steps taken must be properly reported and their execution must be properly monitored (lab journals, progress reports, documentation of arrangements and decisions, etc.).
   - Raw research data are stored for at least ten years. These data are made available to other scientific practitioners upon request, unless legal requirements dictate otherwise.
   - Raw research data are archived in such a way that they can be consulted at all times at a minimum expense of time and effort.
   - Research complies with all relevant legislation and regulations, including:
     - the Personal Data Protection Act (Code of Conduct for Research & Statistics);
     - the Medical Scientific Research with People Act;
     - the Code of Conduct for Health Research;
     - the Experiments on Animals Act.
   - Ownership of the research data is subject to intellectual property laws (Copyright Act, Patent Act, Databases Act), the Collective Labour Agreement for Dutch Universities (Article 1(20-23)), and the regulations on Knowledge, Intellectual Property and VU/VUmc Participation, unless otherwise agreed with funding bodies.

For the high-energy physics community that mostly performs research within large international collaborations additional requirements for data storage apply. Data must be accessible from all over the world (e.g. through the LHC data processing centres), for very long timescales. The collaborations typically have a policy to store data and tools so that all obtained results can be checked and re-derived from the raw data, well beyond the lifetime of the experiments.

A.1.3 Diversity

A.1.3.1 Gender balance

Balancing the ratio male/female scientific staff is a focus of the Department. The past and present balance is illustrated in Appendix F.2.5.1. We see that in particular the career development of female scientists from PhD to professor could be improved. Currently, we have a significantly higher percentage of female PhD's than female professors. In order to remedy this imbalance we aim to increase the number of female applicants for all staff positions (tenure track, assistant/associate/full professor). Specific actions include explicitly reaching out to women to apply whenever we advertise a position. Every search committee needs to invite at least one female candidate for the interview round. In 2013, for example, these actions led to the hiring of a female tenure tracker – Elizabeth von Hauff. Furthermore, two female professors (Marloes Groot and Roberta Croce) have been appointed during the evaluation period. Moreover, LaserLaB supports female PhDs with building scientific networks, for example by sponsoring the thematic event 'How to become a professor', aimed at a female audience.

A.1.3.1 Cultural diversity

The department has a highly international staff composition. Over the evaluation period, a total of 27 different nationalities have been employed in the department. In 2016, a fraction of 44% of all staff were of non-Dutch origin. Appendix F.2.5.1 contains a table with the developments over the period 2010-2016.

A.2 UvA Institute of Physics

A.2.1 Organization, composition and financing

The UvA Institute of Physics (IoP) was founded in 2011 and consists of three smaller physics institutes: the **Van der Waals-Zeeman Institute for Experimental Physics (WZI)**, the **Institute for Theoretical Physics Amsterdam (ITFA)** and the **Institute for High-Energy Physics (IHEF)**.

- The WZI performs research in the areas of hard condensed matter, soft matter, and quantum gases & quantum information.
- Researchers at the ITFA perform research in the (partly overlapping) themes soft condensed matter, quantum condensed matter, string theory, theoretical particle physics, astroparticle physics, cosmology, mathematical physics, and history of physics.
- The IHEF is embedded within the Nikhef collaboration, together with fellow institutes of VU and three other universities. Within IHEF, research focuses on both theoretical and experimental particle and astroparticle physics, with participation in the international collaborations ATLAS (at LHC/CERN), KM3NeT, and XENON. As part of the Nikhef collaboration, the research programme of IHEF is not independently laid out, but coordinated within Nikhef. Nikhef has its own Scientific Advisory Council, visiting the institute annually and thereby also addressing the research programmes to which IHEF staff contribute.

Over the evaluation period, the Institute of Physics has tremendously grown, from 98 fte in 2010 to 171 fte in 2016 (see Appendix F.3.2). This growth is primarily caused by successful grant acquisition, Sector Plan funds from the Dutch government and a successful use of the Research Priority Area within the UvA. Research and teaching excellence are the first and foremost goals of the IoP. We proudly note that by number of citations per published paper for instance, the IoP does better than the number 1 on most of the rankings in physics, the University of Cambridge (2016 QS ranking gives 94.9 citations/paper for UvA Physics, against 91.6 for Cambridge physics, see www.topuniversities.com).

Governance

The divisions of IoP are all of roughly equal size in terms of (permanent) scientific staff. The IoP is led by a directorate / management team consisting of the heads of the three divisions, one of which acts as the IoP director, and the institute manager.

The IoP directorate currently consists of:

- Paul de Jong, Director IoP and Head IHEF
- Daniel Bonn, Head WZI
- Jan de Boer, Head ITFA
- Joost van Mameren, Institute Manager IoP

The IoP directorate operates in an informal and collegial manner, in which much of the divisions' strategic and operational matters are effectively delegated to the division heads. The divisions each have a separate tradition of (informal) management, such as via regular staff lunches, where matters concerning research and teaching are discussed on an informal basis.

The IoP support office provides administrative and secretarial support for matters related to HR, ICT, outreach and PR, finance, event organization, website, etc. Specialized services are offered by faculty-level teams for project administration, finance and control, HR and legal advice, communications and outreach.

The IoP is active in a wide range of (physics-specific) outreach activities, such as master classes for excellent high-school students, the maintenance and content creation of the Dutch popular physics web site www.quantumuniverse.nl, and the annual overview conference *Viva Fysica!* for physics teachers and their best pupils. Our main strategy is to do research-inspired outreach: we want to show the general audience (and potential future students in particular) what the current open research questions are and why researchers are so excited about them. To make sure research and outreach stay closely connected, a dedicated position was created in 2016, currently filled by M. Vonk, who spends 40% of his time on research and teaching and 60% on outreach.

A few technical support staff are directly appointed at the IoP. In addition, the Faculty of Science comprises a Technology Centre (TC) providing mechanical and electronic workshop services to all experimental research institutes. IoP alone (through its WZI division) takes up well over 50% of the capacity of TC, indicating the important role of such services in an experimental physics context.

Finance

In 2006, the UvA adopted a full-cost accounting system. In this system, practically all costs of the university's supporting infrastructure (housing, financial, personnel, IT services, library, etc.) are attributed to the institutes. The institutes are compensated for these higher costs in the form of additional direct funding. This not only influences the apparent difference in the ratio of internal to external research funding between experimental and theoretical institutes (as the former need to meet a much higher non-personnel cost base), but also impacts comparisons between such figures for different universities. The development of personnel numbers and other expenditures can be found in Appendix F.3.2. The direct government funding budget allocated to the IoP is characterized by three components:

1. A fixed base amount;
2. A parametrized component that is primarily determined by performance indicators such as the numbers of PhD degrees and undergraduate diplomas conferred, the teaching effort by IoP staff and the annual turnover of externally funded projects;
3. Fixed (often temporary) budgets earmarked for specific strategic goals, such as investments in research priority areas.

Besides direct funding, project funding is obtained from national research funding organization like NWO, FOM and STW, from international sources such as the EU, or from industrial / private partners.

The graph in Appendix F.3.2 shows the budget development of both the direct and external budgets over the past years. Note that the full-cost accounting system used at UvA makes for the fact that acquired project grants do not cover the full overhead costs of a project, which thus has to be covered by the direct funding. Also note that externally funded projects in which IHEF staff is involved are completely administrated through Nikhef and are thus not included in the graph. From the graph it is clear that both the direct funding and the external funding have increased significantly, despite national trends of budget cuts in the type of (fundamental) research carried out at IoP. A large fraction of the external funding consists of personal grants (ERC Starting/Consolidator grants, NWO Vidi/Vici grants) awarded to early to mid-career staff members. This is to a large extent the result of the coherent support programme offered to staff members who apply for grants offering (a) the help of a freelance text editor, (b) structurally organising proofreading sessions by colleagues, and (c) support by a freelance interview trainer to prepare for committee interviews.

A.2.2 Research integrity

A.2.2.1 General reflection on research integrity and culture

Within the UvA and the Faculty of Science there has been increasing attention towards the subject of scientific integrity. This has led to the IoP producing a Code of Conduct on Scientific Integrity, which describes various guidelines, best practices, ethical aspects and escalation mechanisms (see Appendix F.10.2). As to ethical and integrity issues, an important role in the guidance of PhD students and postdocs is played by their supervisors. As a standard university policy, Master's and PhD theses are independently checked for plagiarism using electronic tools such as Ephorus and IThenticate. It is our perception that research integrity is well engrained in the institute at all levels and we are unaware of any significant incidents taking place during the evaluation period.

The experimental particle and astroparticle physics research within IHEF is typically performed within international collaborations of researchers. Since publications are co-authored by all collaborators, a high degree of attention is devoted to the integrity of the process by which results are obtained, and to an internal review of these results before they are published. The collaborations typically require that only validated tools and validated data sets be used in data analysis. Data sets in which a new signal may hide are typically "blinded" to prevent researcher bias. Internal reviews of all results in the collaborations take place at multiple levels: within dedicated physics analysis groups, by review boards composed of experts, and collaboration-wide before publication.

A.2.2.2 Data storage

Over the evaluation period, national and international trends as well as increasingly stringent boundary conditions set by funding agencies and publishers have increased the importance of proper storage of research data and metadata. In line with these developments, the UvA has developed tools that help researchers to live up to these external requirements, which are summarised at rdm.uva.nl. These include the recent introduction of *figshare* for all UvA researchers to enable the persistent and safe storage of research data, with ample sharing options either with peers or publicly using DOIs. These tools facilitate the paradigm of open access to research data.

The data storage system still in use at the IoP (in particular for experimental research at the WZI) is based on local harddrives with multiple backups. Each PhD student has a numbered HDD and these are left with the PI at the end of the contract, together with the lab notebooks that provide the relevant metadata. In addition to this, several groups use network drives that automatically back up data from the different experiments. It is expected that most of the local solutions for data and metadata storage will be gradually replaced by cloud-based solutions such as *figshare*.

Traditionally, the (astro)particle physics community with its collaborative mode of doing research has pioneered large-scale research data management policies for storing, preserving and distributing of both raw and processed data. Data must be accessible from all over the world (e.g. through the LHC data processing centres) over very long timescales. The collaborations typically have a policy to store data and tools in such a way that all obtained results can be checked and rederived from the raw data for the foreseeable future, well beyond the lifetime of the experiments. Building on this practice, the providing of open access to raw data (typically after a short proprietary period) has rapidly gained ground in (astro) particle physics.

A.2.3 Diversity

A.2.3.1 Gender diversity

Women in the Netherlands are notoriously underrepresented at all levels of the sciences, in particular in physics. The IoP is no exception. We will refrain from repeating parts of this debate of the last few decades but do note that lack of diversity in the sciences is a complicated issue, the cause of which is complex and spread across many parts of society. It is already manifest in high-schools and arguably shaped at a very young age. Although role models can make a difference, we are not in favour of a strict top-down approach based on e.g. enforcing percentages. Our main policy is to promote awareness of diversity and diversity-bias, and to create a safe, supportive and inclusive work environment. Some concrete measures in this respect include:

- We include at least one female member in hiring and promotion committees.
- We have a separate discussion of female/minority applicants for job openings, and similarly for seminar speakers and e.g. participants for workshops/conferences that we organize.
- IoP staff members can flexibly organize their work to find a balance in combining work and family (e.g. leave, part-time work, working from home), within reasonable limits.
- We actively participate in the Women in the Faculty (WiF) forum (through Alejandra Castro, who acts as chair).
- IoP staff members can submit special funding requests, e.g., for travelling to a conference with their families or a babysitter.
- With outreach activities we try to (modestly) address the diversity issue at the high-school level.
- We actively participate in the GENERA project and other international projects aimed at improving gender diversity.
- We offer career support for partners of new hires.
- Specifically for ITFA there is a special Delta ITP call for PhD positions for female applicants only.

Both at a national level and at the University of Amsterdam, various programmes dedicated to reducing the gender unbalance have been developed. The IoP has in recent years made an effort to catch up in this area, keenly making use of these programmes. In particular, IoP has actively used opportunities to increase the number of women among the scientific staff, in particular using funds from the national Sector Plan for Physics and Chemistry (Noushine Shahidzadeh) and the MacGillavry Fellowship at the UvA's Faculty of Science (Miranda Cheng and Katerina Dohnalová-Newell). Appendix F.2.5.2 contains a graph of the development of the number of staff at the various levels over the past years, broken down by gender.

In particular among new hires at the junior staff level (assistant professor or UD), the fraction of women has steeply increased (see the graph in Appendix F.2.5.2). Since most of these new staff members have been appointed on a tenure track and thus with a clear and fast career perspective, we are confident the future staff composition will be less skewed. The overall female fraction among permanent staff (tenure trackers included) has nonetheless only just passed the 10% limit, still quite far below the 20% goal formulated by FOM several years ago for the Dutch physics community to achieve in 2020.

A.2.3.2 Cultural diversity

The Institute of Physics is proud to host a highly international community. The table in Appendix F.2.5.2 shows the fraction of non-Dutch employees over the years, as well as the increasing number of unique nationalities represented among our employees. The graph in Appendix F.2.5.2 shows that, over the evaluation period, this international character is increasingly reflected in the composition of the permanent staff. Since 2014, the number of Dutch PhD students has increased.

A.3 PhD programme

A.3.1 Context, supervision and quality assurance

The duration of PhD programmes in the sciences in the Netherlands is 4 years. PhD students are in most cases appointed during that period as regular employees with a competitive salary. Also when a PhD student is funded by certain EU projects or other international sources where only 3 years of funding are provided, an additional fourth year is made available by the department. Within physics, PhD students are either employed by the university or by the national funding agency NWO (until 2017 for physics through its daughter organization FOM). Besides fully funded PhD positions (the vast majority), some PhD students bring their own scholarship. Such bursary students are treated equally as much as possible.

Physics PhD students at UvA and VU all have one to three primary supervisors consisting of staff members who are ultimately responsible for the quality of the promotion and who do the actual supervision. In the Netherlands, only full professors can traditionally confer PhD degrees, and the full professor associated in this capacity to the PhD student is denoted as the "promotor". If the promotor is not the primary supervisor, his/her role is in practice limited. Therefore, the new legislation that allows, under certain conditions, associate and assistant professors to act as promotor as well is widely embraced.

Before the start or at the latest during the first few months of each PhD project, a Training and Supervision plan is written, which describes the overall direction of the research project, the schools and courses to be attended, and various aspects of the supervision such as minimum frequency of contact between PhD student and supervisor(s).

During the annual assessment and progress meeting, several important aspects are discussed: general progress of the PhD, mutual expectations, level of scientific independence, possible schools and conferences to attend, possible courses to follow, things that can be done to support the post-PhD career, etc. Besides formal annual assessment and progress meetings, the format of the day-to-day supervision is mostly left to the supervisor(s) and the PhD student. The universities also have several confidentiality advisors who can be consulted.

After a PhD student completes the thesis manuscript and it has been approved by the supervisor(s) and promotor, it is sent to a PhD committee of up to 7 experts who judge whether or not the thesis is of sufficient quality to be admitted to the formal defence. When this committee has approved the manuscript, the thesis is printed and the formal defence (consisting of a 45-minute public question session by the same committee) is arranged.

Besides taking part in courses and training (see next section), every PhD student is expected to contribute to teaching. As little distinction as possible is made to the nature of the contract of the PhD student (university, FOM/NWO, scholarship) or background (Dutch, non-Dutch). In principle all PhD students are expected to contribute up to 10% of their time to education (roughly equivalent to at most 24 ECTS of teaching assistantship). The preferences of the PhD student and supervisor are taken into account as much as possible in the distribution of educational efforts over his/her contract duration. In practice an effort is made to exempt the final year from educational tasks.

A.3.2 Courses for PhD candidates

There is an obligatory educational component for all PhD students. This is realized for instance in Graduate Research Schools like the Dutch Research School for Theoretical Physics or the Research School for Subatomic Physics. It includes courses given by experts, going beyond the level offered in the MSc programme. Details on this educational part depend on the different institutes/groups involved. Furthermore, all PhD students are expected to follow a small, partially mandatory “soft skills” programme[1].

In some cases, PhD students are offered the possibility to independently identify relevant course modules on an *ad hoc* basis. The institute or department typically provides a financial contribution in case the research group is lacking funds.

A.3.3 Selection and admission procedures

In general, PhD vacancies are advertised through websites (university or NWO/FOM, Academic Transfer, etc.) and via the personal network of the supervisor(s). The selection of the candidates is done by the supervisor(s) and can include a visit of a few top candidates or a Skype interview. The involvement of other staff members in the selection procedure is an important part of the selection procedure.

[1] The courses organized by the UvA’s Faculty of Science are as listed at gss.uva.nl/current-phds/skills-development/faculty-level/faculty-program.html, for the VU Faculty of Science at www.vu.nl/en/research/taking-phd/index.aspx. PhD students employed by FOM (now called NWO-I) have a separate set of mandatory/optional courses described at www.nwo-i.nl/en/personnel/information-for-phd-students-and-postdocs/special-courses-for-trainee-researchers/.

A.3.4 Supervision of PhD candidates and guidance to the labour market

Most aspects of the day-to-day supervision of PhD candidates have been described above. During annual reviews, but also often informally, future plans and ambitions of PhD candidates are discussed. If PhD candidates intend to leave academia and need additional training in order to be able to enter a particular sector, the supervisor(s) will try to facilitate this. Similarly, if PhD candidates are interested in continuing as a postdoc, their supervisor(s) will coach them, e.g. help them to arrange visits to potential employers, etc.

Some of the courses offered to PhD students are aimed at helping PhD candidates think about their future well before the end of their contract. An annual two-day career event is organized for all MSc and PhD students and postdocs in Physics and Astronomy at UvA and VU, where one day is concerned with academic careers and the other with non-academic careers. The programme of these Career Days contains presentations by alumni and recruitment experts, as well as feedback sessions in which participants get suggestions to improve their CVs.

A.4 BSc and MSc education

The educational programmes in which our staff members teach are not evaluated as part of the present research evaluation and do thus not form a core part of the present document. To provide some context, the most relevant aspects regarding teaching are introduced below.

A.4.1 BSc Natuur- en Sterrenkunde (Physics and Astronomy)

The BSc programme in Physics and Astronomy is taught primarily by teachers from the Department Physics and Astronomy of the VU, the Institute of Physics, and the Anton Pannekoek Institute for Astronomy. In 2014/2015, the two separate BSc programmes of UvA and VU were merged into a single joint degree programme. The complementarity of the research programmes of UvA and VU now provides students with a broader portfolio of electives, internships and therefore career perspectives. Since several years, the programme has attracted a stable influx of well over 100 first year students. Including students in the dual Physics/Mathematics BSc programme and beta gamma students with a physics major (see below), this brings over 150 students to the classroom. The third year of the programme was recently adjusted to being taught in English, enabling a more active exchange of students (both to and from Amsterdam). It is currently being discussed whether the entire programme should be taught in English to attract more international talent to Amsterdam already at the BSc level. The present programme director is Marcel Vreeswijk.

A.4.2 MSc Physics and Astronomy

UvA and VU have joined forces in the Master's programme Physics and Astronomy, taught entirely in English. The programme has several MSc tracks, which are tightly, almost one-on-one linked to the participating research units. These are:

- Advanced Matter and Energy Physics
- Astronomy and Astrophysics
- Gravitation, Astro- and Particle Physics
- Physics of Life and Health
- Science for Energy and Sustainability
- Theoretical Physics

The programme has attracted 80-100 first-year students for years, many of whom transfer from our own BSc programme. The number of students in the current cohort has now risen to over 100.

The MSc programme became a joint degree programme in 2015/2016, when at the same time the MSc Physics programme (which had been offered as a joint programme for over a decade by UvA and VU) was merged with the Astronomy and Astrophysics programme of UvA to become one joint degree programme in Physics and Astronomy. The present programme director is Ivo van Stokkum, who succeeded Wim Vassen in 2017.

A.4.3 Involvement in other educational programmes

Apart from the above joint programmes, our staff is involved in various other multidisciplinary BSc and MSc programmes at UvA or VU.

Together with the Department of Chemistry and Pharmaceutical Sciences at VU and the VU Medical Centre (VUmc), the Department of Physics and Astronomy at VU runs the Medical Natural Sciences (MNS) BSc and MSc programmes, combining science (in particular physics, chemistry and math) with medicine. The BSc programme attracts about 80 first-year students. Marloes Groot is currently director of both programmes and numerous members of the VU Department of Physics and Astronomy are involved in teaching. Many MNS students perform their BSc or MSc internships at LaserLaB.

In addition, the department at VU is involved in the BSc and MSc programmes Science, Business & Innovation (SBI) of VU, which in the past years have attracted about 90 and 30 first-year students, respectively. SBI is a collaboration between the Faculty of Science, the School of Business and Economics, and the Faculty of Social Sciences of VU. It aims to integrate both the scientific and the business side of innovations. Members of the VU Department of Physics and Astronomy and recently also teachers from UvA's Institute of Physics are involved in teaching physics to SBI students and supervise BSc and MSc students during their internships (which are mostly performed at companies outside VU).

UvA staff members are modestly but increasingly becoming involved in the MNS and SBI programmes.

Finally we would like to mention the involvement of teachers of both universities in the Liberal Arts and Sciences programme of the Amsterdam University College (AUC, a joint educational institute of UvA and VU), taught entirely in English. Furthermore, the UvA's Institute for Interdisciplinary Studies offers a broad and interdisciplinary BSc programme called 'beta gamma', combining exact and social sciences. Second-year students who choose the Physics track within this programme essentially follow large parts of the BSc programme Physics and Astronomy.

A.4.4 Educational leadership

Several staff members hold key leadership positions in the teaching organization of both universities. Besides the programme directors mentioned above, Jan de Boer (UvA, ITFA) served as acting Director of Education of the UvA's Faculty of Science and Marloes Groot (VU, LaserLaB) has been responsible for Physics education within the Board of the Faculty of Sciences at VU. Furthermore, staff members take on educational leadership roles as programme directors, MSc track coordinators, or as members of the Examination Board or the Board of Studies.

A.5 UvA-VU collaboration

A.5.1 Developments over the evaluation period

As a result of many years of intensifying collaboration in education (see above), through the Sector Plan for Physics and Chemistry, UvA's IoP, the VU Department of Physics and Astronomy and UvA's Anton Pannekoek Institute for Astronomy have been joining forces to form a joint *Institute of Physics and Astronomy* (IPA). In 2012-2013, the Science Faculties of UvA and VU have even attempted to join forces at the faculty-level to create a single Amsterdam Faculty of Science. This process was eventually voted down, but the wish to strongly collaborate in the Physics and Astronomy domain stayed alive nonetheless. The Deans of the two Science Faculties have then chosen to facilitate a process to create joint Institutes in areas where the potential synergy was considered highest. The idea of the IPA sprung from this strategy.

Starting from the existing strengths of the founding institutes, a plan was created to constitute a broad, exciting environment of research and study in physics and astronomy, with great appeal to students and researchers and strong connections to other institutions in the region and society at large. The idea of IPA was to become a robust, broad, and world-leading centre of excellence that fits into this long tradition of research and teaching in physics and astronomy and their many applications, expanding our knowledge and passing it on to future generations. Most potential added value was expected in areas where combining efforts is particularly beneficial: creating higher visibility as a centre of excellence across the breadth of physics and astronomy, more efficient provision of excellent facilities (e.g., experimental facilities, high-performance computing resources), joint advertising and recruiting. The IPA would comprise a total of 350 PhD-level researchers, and an even larger number in associated nearby institutes (Nikhef, AMOLF, ARCNL) in Amsterdam, constituting a level of effort and critical mass that matches the foremost centres of physics and astronomy in the world.

Together with the Deans and University boards of UvA and VU, a major relocation plan was prepared (in which also other disciplines would be redistributed over the two campuses of UvA and VU). For Physics and Astronomy, the clear focal point was at Amsterdam Science Park, creating a concentrated hub of activity.

To the dismay of the entire physics and astronomy community of UvA and VU (staff and students), the plans for the creation of IPA on Amsterdam Science Park were eventually voted down in the spring of 2017 by the participating bodies at the university level – with a particularly strong role for the central student council at the UvA. The concerns raised by the participating bodies were in fact unrelated to the plans for our domain, but instead focused on the relocation plans for the joint Informatics institutes and in particular their teaching programmes. Since the relocation of the VU Physics was coupled to the relocation of the UvA informatics to the VU campus, the planned move became impossible.

A.5.2 Present situation and strategic outlook

The mission of IPA to become a robust, broad, centre of excellence, attracting excellent researchers and students is still vividly alive. It is our ambition to have positioned ourselves in the European top for physics research and education, but also to be recognized as such, with the corresponding reputation.

We are confident that joining forces of individually strong institutes will help us to seize more opportunities, be more robust, and be more visible. We are more efficient and better equipped when we can share facilities and instruments.

Even though the unilocation of IPA will unfortunately not be realised in the foreseeable future, many of the potential advantages of cooperation remain. UvA and VU Physics and Astronomy have expressed their desire to keep cooperating in the new circumstances of bi-location.

The decision on bi-location being quite fresh (summer 2017), the discussions on the shaping of the cooperation are certainly not finished, and no final conclusions can be drawn yet. In particular, the ambition level that we can achieve, and the degree to which we will and should form one common entity both among ourselves and to the outside world, are under discussion.

A number of planned common activities can be maintained also under the new circumstances. These include:

- Common seminars, and better awareness of relevant seminars elsewhere in Amsterdam;
- A joint visitors program;
- Joint talent attraction, shared recruitment;
- Continuation of the successful joint BSc and MSc programmes, and the marketing thereof.

IPA offers great opportunities for interdisciplinary projects between groups at UvA, VU, the Amsterdam Science Park, and the medical centres of both universities. Such cooperation under the new circumstances of bi-location requires the minimisation of bureaucratic hurdles, and the creation of an environment where initiating common projects is easy and not hampered by technicalities. This should include travelling from one campus to the other, and easy and non-bureaucratic access to facilities at other locations. The efficient sharing of instruments, however, will become more difficult, and solutions will have to be creatively sought after.

Since the revisiting of the IPA plans among ourselves has only just begun, we propose to evaluate the research units discussed in Chapters -E primarily on their individual merits, both in terms of past performance and future strategy and potential.

B. VU Institute for Lasers, Life sciences and Biophotonics Amsterdam (VU LaserLaB)

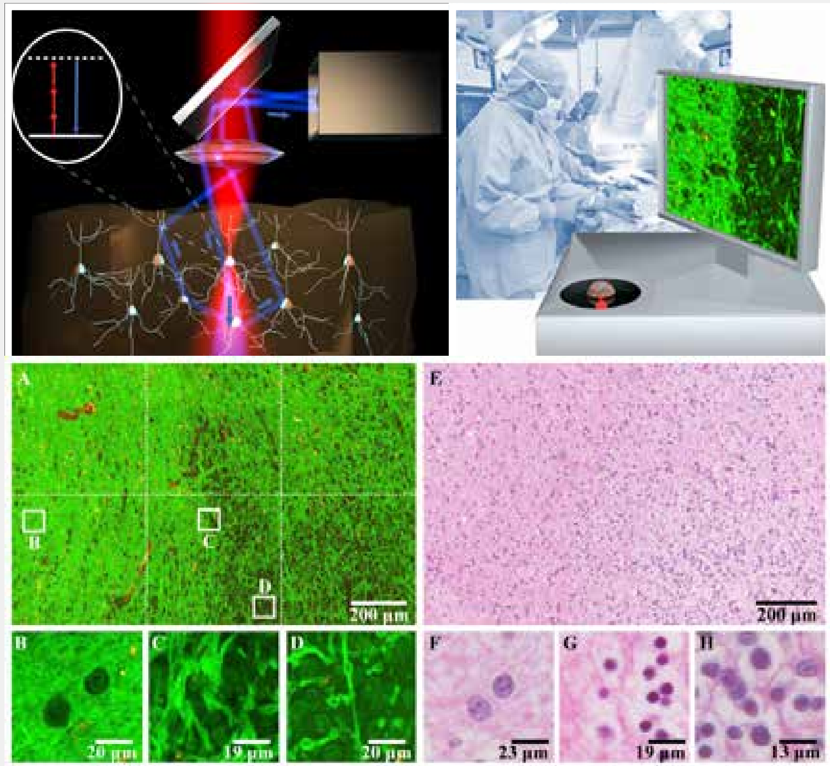
B.1 Introduction

LaserLaB Amsterdam is the research institute of Lasers, Life and Biophotonics, focusing on fundamental physics, physics of life and physics of energy. Although LaserLaB also includes groups at VU Biology, UvA Chemistry, AMC and VUmc, this chapter focuses on the VU Physics and Astronomy research sections, which are the majority of LaserLaB.

LaserLaB Amsterdam is a founding member of LASERLAB-Europe, a European consortium of 30 major laser laboratories jointly providing access to international researchers and performing joint research, financed by the EU. From 2010-2016, LaserLaB Amsterdam has been very successful in performing ground-breaking research and obtaining external funding. Among the most important developments are:

- 2010: NWO Vidi Frese; NWO Vici de Boer; ERC Starting Grant Wuite; ERC Advanced Grant van Grondelle; FOM programme grants Ubachs & van Grondelle
- 2011: Hiring of Croce; NWO Vidi Knoop; NWO Vici Peterman & Croce; ERC Consolidator Croce
- 2012: Hiring of Roos & Stephens; NWO Vidi Koelemeij; NWO Vici Kennis; FOM programme grant Peterman

Highlight



LaserLaB researchers showed that third-harmonic generation microscopy (top left) can be used to produce images of brain tumour tissue (lower left) that are comparable in quality to the golden standard histopathology (lower right). These images are, however, obtained in real time, i.e., within 1 minute instead of up to 16 hours. With a table-top device (top right), this enables real-time feedback to the surgeon during surgery (Kuzmin et al., Biomed Opt Express 2016). This LaserLaB technology is now commercialized by spin-off company TRITOS Diagnostics.

- 2013: Hiring of Von Hauff; NWO Vidi Roos; ERC Consolidator Iannuzzi; VU university research chair (URC) professorships Iannuzzi & Peterman; professorship Eikema; foundation of ARCNL
- 2014: FET-Open programme Wuite
- 2015: ERC Advanced Grant Ubachs; Roos leaves VU for Groningen University
- 2016: Hiring of Heller; ERC Advanced Grant Eikema; FOM programme grant Eikema (completely VU); professorship Kennis; MacKintosh leaves VU for Rice University
- 2017: NWO Vidi Heller; NWO Gravitation grant 'Building a Synthetic Cell' (Wuite).

These new hires, promotions and grants have resulted in excellent scientific output. In addition, four start-up companies have emerged from LaserLaB research groups: Optics11 (Iannuzzi), LUMICKS (Heller, Peterman & Wuite), OPNT (Koelemeij) and TRITOS Diagnostics (Groot).

B.2 Research description

B.2.1 Organization, composition and financing

The mission of LaserLaB is to perform ground-breaking scientific research focusing on the interaction of light with matter. Research topics span from single atoms and molecules, via living cells and tissue to sustainable energy sources. Within LaserLaB, cross-disciplinary research is conducted in a close collaboration between physicists, chemists, biologists and physicians. The research is motivated by societal questions (Life, Energy) and pure curiosity (Fundamental Physics). The experimental setups within LaserLaB are of a "table-top" nature/scale. Many of the

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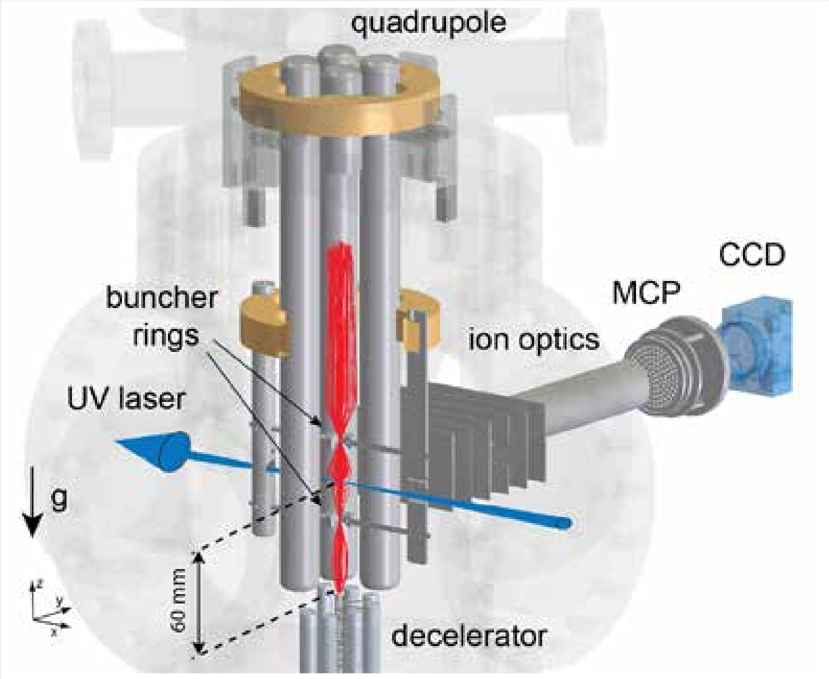

LaserLaB researchers recently demonstrated the world's first molecular fountain. In these experiments, ammonia molecules are decelerated and cooled using electric fields, launched upwards and observed as they fall back under gravity 266 milliseconds later. The long interrogation time paves the way for new sub-Hz precision experiments to test fundamental physics with molecular systems (Cheng et al., Phys Rev Lett 2016).

setups are dedicated, worldwide unique instruments. Within LASERLAB-Europe, an Integrated Infrastructure Initiative funded by EU, LaserLaB provides access to its advanced laser-based instruments to scientists from Europe and beyond. In addition, LaserLaB participates in EU Joint Research Activities together with other members of LASERLAB-Europe. Currently, LASERLAB-Europe is in its fourth iteration (12/2015-12/2019). In particular the transnational access is a very successful mechanism for international, interdisciplinary collaboration.

LaserLaB is led by a director (currently E. Peterman), aided by a management team consisting of members of the constituting research groups. Formally, LaserLaB Amsterdam also consists of research groups outside of VU Physics and Astronomy: VUmc (A. Lammertsma), UvA Chemistry (W.J. Buma) and AMC (T. van Leeuwen). These research activities are not considered in the current evaluation.

Theme	**Members Laserlab** *(Part-time appointments and professors by special appointment in italic)*	**Connects to**
Biophotonics and Medical Imaging	De Boer, Groot, Iannuzzi, Ariese, Verdaasdonk	VUmc, AMC
Physics of Living Systems	Wuite, Peterman, Heller, Stephens, *Koenderink (AMOLF), ten Wolde (AMOLF), Shimizu (AMOLF), MacKintosh (Rice)*	AMOLF, UvA ITFA, UvA Soft Condensed Matter Group
Biophysics of Photosynthesis	Croce, Dekker, Kennis, Frese, van Stokkum, van Grondelle, *Robert (CEA Paris)*	Solardam, UvA HIMS, UvA Hard (and Soft) Condensed matter: Optoelectronic Materials
Physics of Energy	Wijngaarden, von Hauff	Solardam, UvA HIMS, UvA Hard (and Soft) Condensed matter: Optoelectronic Materials
Atoms, Molecules & Lasers	Ubachs, Eikema (both part-time appointed at ARCNL), Bethlem, Vassen, *Aben* (SRON), *Frenken* (ARCNL), *den Boef* (ARCNL), *Visser* (TU Delft)	ARCNL, SRON, UvA Quantum Gases and Quantum Information (QG&QI)

The research performed within LaserLaB is well positioned to participate in national and international funding initiatives. LaserLaB research collaborate closely with partners at VU, VUmc, UvA and AMC; these include among others the Neuroscience campus, the Amsterdam Institute for Molecules, Medicine and systems (AIMMS), the institute Quantivision, the VU medical centre (Dept. of Radiology and the Imaging Centre); and the physics institutes clusters on the Science Park Amsterdam / UvA campus: AMOLF, ARCNL, and Nikhef.

Finances of LaserLaB research are mostly taken care of at the department level (see Section A.1.1).

Research Focus

LaserLaB aims to be a broad and interdisciplinary research structure covering many aspects of physics; from satisfying our basic curiosity about the world to exploring the foundations of new technologies that may change that world. We aim for excellence in all that we do. *The prime ingredient for that excellence is our human capital.* Primarily, therefore, we aim to create an environment that attracts excellent researchers, stimulates them to excel, and allows them to thrive. Excellent research is what excellent researchers do, not what strategists plan. This does not mean that we should not plan, because larger initiatives require investments and joint efforts of a group of researchers in order to be successful, and in making our choices (especially in recruitment) we should anticipate on the directions our field is likely to evolve into. But our strategy should reflect the ambition of our researchers, and not the other way around, and so it should be flexible, and reviewed regularly and with broad consultation. The five LaserLaB sections, each comprised of several research groups that share lab space and budget and led by a section head, are described below.

- Atoms, Molecules & Laser Physics

The Atomic, Molecular and Laser Physics section carries out research into fundamental physics at the atomic scale. Advanced lasers are being developed to push the limits in measurements at extreme precision in the frequency and time domain. These laser and spectroscopic techniques are combined with tools to manipulate and cool atoms and molecules, in Bose-Einstein condensates, sympathetically cooled ions in traps, and in a molecular fountain. The studies are aimed at finding deviations from the standard model of physics, via testing of quantum-electrodynamic theory in calculable systems (He, He^+, H_2 and HD^+) and searching for fifth forces and a possible variation of fundamental constants. Besides two ERC-A programmes on these subjects, the group is jointly involved in two new NWO-FOM programmes focusing on the “proton-radius puzzle” and on measurement of the electron dipole moment via a molecule (BaF). In addition, the

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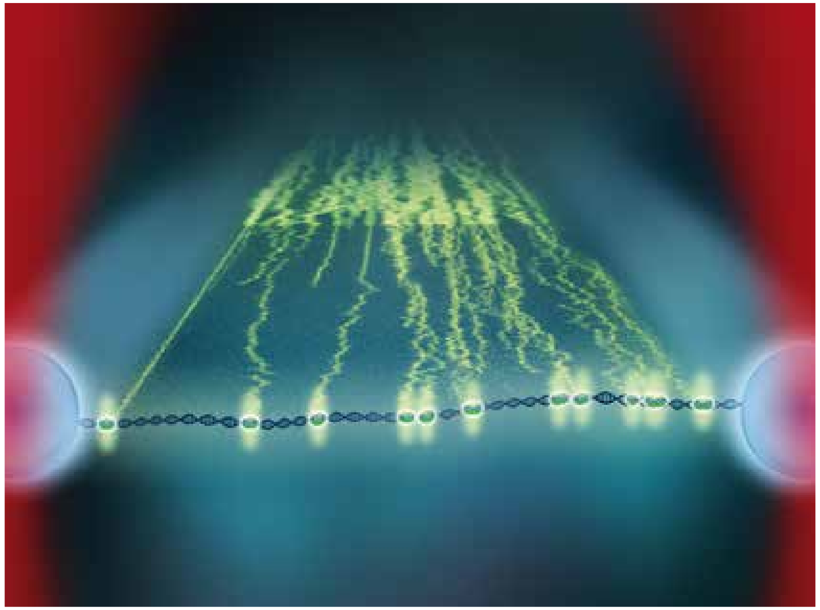

LaserLaB researchers combined optical tweezers with STED super-resolution fluorescence microscopy. This allows the simultaneous manipulation of a piece of DNA (the helical structure) with two micrometer-sized beads (light blue) held in the focus of two laser beams (red), and the imaging at high spatial and temporal resolution of individual proteins (light green) binding to the DNA and diffusing along it. (Heller et al., Nature Methods 2013). This unique LaserLaB technology is commercialized by spin-off LUMICKS B.V.

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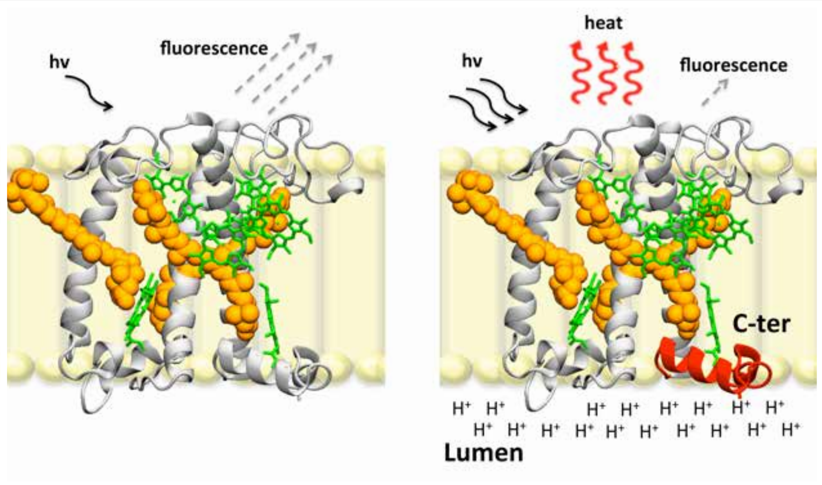


LaserLaB researchers showed how molecular switches regulate photoprotection in green algae (Liguori et al., JACS 2013). Using a combination of mutational analysis and spectroscopy, they unravelled how that the pigment-protein complex LHCSR is involved in fast photo-protective response. Under low-light conditions (left), LHCSR absorbs light and is fluorescent. Under high-light conditions (right), its C-terminus (red) is protonated due to the low pH in the lumen of the photosynthetic membrane (a marker of high-light conditions), activating a conformational switch that results in LHCSR dissipating the absorbed energy in the form of heat.

group brings in the laser physics and spectroscopic expertise used in research at the Advanced Research Center for NanoLithography (ARCNL).

- Biophotonics & Medical Imaging

In the Biophotonics and Medical Imaging section, a wide range of skills and know-how are combined to develop new methods, tools, and instruments for the diagnosis and study of life threatening diseases and impairing medical conditions. Research in the section ranges from the analysis of individual proteins with highly advanced spectroscopic techniques, via the development of nonlinear microscopy for instant pathology, to the implementation of miniaturized Optical Coherence Tomography scanners for endoscopic imaging, and from the development of opto-mechanical micro machined instruments for the measurement of the stiffness of cells and tissues to the use of integrated photonics in cost effective, miniaturized devices.

- Physics of Living Systems

The research in the Physics of Living Systems section focuses on exploring biophysical questions on the level from single molecules to cells and even organisms. A central question is how protein and DNA structural dynamics are related to their function. The aim is to work with increasingly complex assemblies of biomolecules, *in vivo* and *in vitro* in order to investigate the emergent properties from these systems. The section uses a variety of techniques such as super-resolution fluorescence microscopy, single-molecule fluorescence spectroscopy, optical tweezers, tethered particle motion, AFM, as well as combinations of these techniques. The data obtained are related to biochemical studies and used for theoretical modelling. The theoretical physics efforts in this area cover two topics: (1) the fundamental physics of soft matter (of which biological materials are principal examples), in particular structural, mechanical and dynamic properties of these and other soft materials; and (2) the physics of living behaviour, where diverse problems ranging from the motion of small organisms to the dynamics of human cognition are addressed.

- Biophysics of Photosynthesis

The main interest of the Biophysics of Photosynthesis section is to understand the molecular basis of photosynthesis in order to extract the building principles of the light-to-energy conversion machinery, and to use them to improve photosynthesis efficiency in natural systems and guide the design of hybrid and artificial systems. The section analyses the photosynthetic apparatus at different levels of complexity, from single molecules to the whole organism, which can be a bacterial photosynthetic cell or a plant. The effort in photosynthesis is complemented by the study the conversion of light into a biological signal by photoreceptors. The section exploits a large number of techniques varying from state-of-the-art spectroscopies, biochemistry and genetics. Furthermore, advanced computer modelling of experimental data is applied.

- Photo Conversion Materials

The Photo Conversion Materials section has expertise in the synthesis and characterization of functional photoactive materials. There is particular focus on studying opto-electronic phenomena at interfaces, such as semiconductor-semiconductor, semiconductor-metal and solid-liquid interfaces. The section specializes in frequency-resolved electrical techniques, such as impedance spectroscopy and intensity modulated photocurrent spectroscopy, together with theoretical modelling and simulations to describe time-resolved opto-electronic processes in photoactive materials. The section is currently establishing novel measurement approaches, which combine frequency-resolved electrical measurements with optical spectroscopy to study structure-function properties and electron-phonon coupling in molecular and hybrid semiconductors.

B.2.2 Strategy and targets

To build further on the recognized strength of VU Physics and Astronomy and LaserLaB, we have kept our strategy focused on the following three key points:

a. **Scientific excellence**. As discussed above, LaserLaB is committed to scientific excellence and we stimulate our sections to push the frontiers of science. We stimulate this excellence by searching (and finding) very good staff members. Some of our recent search efforts have led to large pools of good candidates of which we had the opportunity to select highly competent researchers. Moreover, once employed, we follow, advise and assist whenever possible so that the scientists can excel. Finally, by embedding each PI in a research section centred on a specific topic we are able to build focus and mass which helps strengthen the research productivity and quality.
b. **Earning power**. With regards to financing our research effort, the VU Physics and Astronomy staff is focused on obtaining external funding. The emphasis over the years has been on hiring talented young people, with a clear, independent research profile, who are highly competitive in the personal grant schemes of NWO (Vidi, Vici) and ERC. In the financial plan of 2009 it has been calculated that one NWO Vici or ERC per 5 years would be sufficient for keeping the department financially viable. To be successful in the personal grant schemes, it was deemed essential to give staff members substantial freedom to develop their own research lines and to show their research excellence. To this end, the old, hierarchical structure of research groups led by one full professor has been abandoned and a flatter structure has been created in the research groups, allowing all academic staff members to develop themselves and their research lines. At the same time, a clear research focus has been kept within the department, i.e., on the research topics outlined above, in order to create synergy and critical mass within the research sections.
c. **Valorisation**. As a response to trends within Dutch society and the university, and aided by the involvement of the department in the Science Business and Innovation BSc and MSc teaching programmes, growing emphasis has been on commercialization of scientific results, by applying for patents, starting

small companies and increasing contacts with industry.

d. **Collaboration with UvA Physics and Astronomy**. Over the last years it has been our strategy to find ways to further strengthen our interactions both in education and research with UvA Physics and Astronomy, to create a research and education institute for Physics and Astronomy that can compete in size and quality with the best in Europe.

B.2.3 Performance indicators

a. **Scientific excellence**. A standard performance indicator is the number of publications and citations. Moreover, the number of invitations to speak at workshops and conferences, to lecture at schools and give colloquia, is an essential indicator of quality as well. Other important performance indicators are the number of PhD theses, individual and collaborative grants obtained, involvement in (inter)national collaborations, prizes and distinctions, editorships, prestigious memberships, etc. The ability to attract talent as evidenced by the number of applications for PhD, postdoc and staff openings is also a good indicator of the international standing of the institute. Moreover, the average PhD duration provides a measure of our ability to supervise and lead research projects. In addition, LaserLaB provides transnational access to its unique facilities within the LASERLAB-Europe consortium. The success of this access can be measured in access days provided and quality and quantity of the resulting scientific output (publications).

b. **Earning power**. Earning power can be judged from the number of grants obtained, personal grants (NWO Vidi & Vici, ERC, CW Top), collaborative grants (FOM programme, FET Open, HFSP) and national grants (FOM projectruimte, CW echo, ALW open competition, STW).

c. **Valorisation**. Regarding societal relevance, given our position, indicators are (i) the number of outreach activities and (ii) valorisation/start-up activities.

B.2.4 Results achieved

a. **Scientific excellence**. Scientific output has been excellent and led to a constant stream of PhD graduates and excellent publications (see appendices). Highlights were:

- Demonstration of the world's first molecular fountain (Cheng et al., PRL 2016). The strongest limit on a fundamental constant of nature (Bagdonaite et al. Science 2013). Ramsey spectroscopy with a frequency comb in the extreme ultraviolet (Kandula et al., PRL 2010). Precision metrology in quantum degenerate gases (van Rooij et al., Science 2011).
- The development of novel minimally invasive optical techniques resulted in third-harmonic generation microscopy for real-time pathology of brain tumours (Kuzmin et al, Biomed Opt Express 2016), the nearly complete mapping of the vasculature down to the capilaries with Angio-OCT (Braaf et al., Opt Express 2012) and polarization properties of the human retina (Braaf et al., Biomed Opt Express 2014).
- Further development of optical tweezers and fluorescence microscopy to allow STED super-resolution microscopy (Heller et al., Nature Methods 2013) and application to DNA bridging by DNA-repair proteins (Brouwer et al., Nature 2016). Quantification of C. elegans motility to reveal new reorientation behaviour (Broekmans et al., eLife 2016).
- Revealing the molecular mechanisms (Liguori et al. JACS 2013) and the role of individual proteins (Dinc et al. PNAS 2016) in the ON/OFF switches of the photosynthetic membrane. Photoactivation mechanism of the plant photoreceptor UVM8 (Mathes et al. JACS 2015). Role of quantum coherence in photosynthetic charge separation (Romero et al., Nature Physics 2014). Highest reported photocurrent for a reaction center complex on an electrode (Friebe et al., Adv Funct Material 2016).
- In cooperation with Merck Chemicals electrical transport in self-as-

sembling, liquid crystalline dyes was studied. It was found that carrier mobility in organic films is determined by a complex interplay between intermolecular interactions and long-range order (Tchamba Yimga et al., ACS Appl Mat & Int 2017).

LaserLaB researchers are frequently asked to write reviews or perspective articles in prestigious journals, including Romero et al., Nature 2017; Vassen Science 2017; Ubachs Science 2016, Croce Science 2015; Prevo et al., Chem Soc Rev 2014; Heller et al., Chemical Reviews 2014.

Apart from publications, LaserLaB researchers are frequently invited to international conferences and have obtained many other tokens of national/ international recognition. Examples are: VU University Research Chairs (Iannuzzi, Peterman), FOM Physics Thesis Prize (Bagdonaitė), Optical Society Fellow (de Boer), Fellowship of the American Physical Society (MacKintosh, Ubachs), Humboldt Research Prize (Van Grondelle), membership and Academy Professorship KNAW (Van Grondelle), G.G. Stokes Prize (de Boer), Templeton Prize (Ubachs), membership of KHMW (Royal Holland Society of Sciences and Humanities; Croce).
Furthermore, two postdoc advisors of LaserLaB researchers have been awarded Nobel prizes (Moerner, Hänsch). In addition, LaserLaB researchers have organized major international conferences including: 17th International Congress on Photosynthesis Research (2016, Croce) and the European Conference on Spectroscopy of Biological Molecules (2017, Groot). LaserLaB researchers are frequently asked to review grant proposals and research articles (e.g., Croce is member of the Board of Reviewing Editors of Science Magazine) and serve on editorial boards of international journals like Biophysical Journal (Wuite); BBA-bioenergetics (Croce); Journal of Molecular Spectroscopy, Photonics, Molecular Physics (Ubachs); PCM Biophysics (van Grondelle).

In addition, the instrumentation of LaserLaB is renowned, with many unique instruments. The access LaserLaB provides to its facilities via LASERLAB Europe is highly successful: LaserLaB Amsterdam is one of the institutes providing most access of all partners in the European consortium, resulting in many collaborative research papers.

b. **Earning power**. LaserLaB researchers have been very successful in obtaining external funding. In particular, many VU physicists have obtained prestigious personal grants (6x NWO Veni, 4x NWO Vidi; 4x NWO Vici; 10x ERC). In addition, LaserLaB researchers have been successful in leading collaborative grants (EU FET Open & 4x FOM programme). In addition, many other national and EU grants have been obtained, including FOM projectruimte, ALW open competition, CW Echo.
c. **Valorisation**. Currently, four companies carry out spin-off research activities related to the work of LaserLaB researchers:

- Optics11 (Iannuzzi): sensing instruments based on optical fibers.
- LUMICKS (Heller, Peterman, Wuite): single-molecule instruments for life science research.
- OPNT (Koelemeij): Optical Positioning, Navigation and Timing.
- Tritos Diagnostics (Groot): third-harmonic generation microscopy for medical applications in cytology and histology.

All four companies are located in the VU Science building, creating a truly entrepreneurial atmosphere. In addition to these startup companies, VU Physics and Astronomy is deeply involved in the Demonstrator Lab. This lab, which is also located in the VU Science building (director: Iannuzzi), is a facility for students and researchers where bright ideas are transformed into tangible customer added value.

Another highly successful activity is the involvement of VU Physics and Astronomy in ARCNL, the Advanced Research Center for NanoLithography, a joint research institute between industry (ASML) and VU, UvA and NWO focusing on fundamental physics with a relevance to key technologies in nanolithography. LaserLaB researchers Eikema and Ubachs partly work in this institute and former LaserLaB researcher Witte has completely transferred his research efforts.

In addition, LaserLaB researchers have been involved in outreach activities ranging from public lectures with classical music (Peterman 14/05/2014) to radio interviews (van Grondelle 03/03/2013), national newspaper interviews (Ubachs 24/03/2012; Bethlem 14/11/2016) and open days / open laboratory. LaserLaB researcher Frese has, together with artist Ivan Henriques, designed an Algae Powered Robot (APR), which has been on public display and has received international attention. A more comprehensive list with links can be found in Appendix F.8.1.

d. **Collaboration with UvA Physics and Astronomy**. As discussed above, over this evaluation period, a lot of effort has been devoted to increasing our collaboration with UvA Physics and Astronomy. The Physics and Astronomy BSc and MSc programmes have been merged ("joint degree"). The move of most of LaserLaB to Science Park Amsterdam, which also hosts our UvA colleagues, in order to form a single institute, mostly on one location, however, will not be realized. As a consequence, LaserLaB will remain at the VU/Zuidas campus. We are currently adapting to this new reality: a bilocation of VU/UvA physics and astronomy. For LaserLaB, a key focus is now on the construction of new laboratory facilities on the VU/Zuidas campus, which is currently in the planning phase.

B.2.5 Own assessment of quality, relevance and viability

At this moment in time, VU Physics and Astronomy / LaserLaB is doing very well. This is evident from the large amount of external funding acquired, including many prestigious personal grants, but also from the scientific output (publications) and other recognitions. All sections are internationally renowned; all consist of several academic staff members (four of the five sections have at least two full professors). Another important development is valorisation: over the past years, LaserLaB researchers have been very active in starting companies commercializing their scientific results. LaserLaB research is deeply embedded in several education programmes: the joint UvA/VU Physics and Astronomy BSc and MSc programmes and the interdisciplinary programs Science Business and Innovation, and Medical Natural Sciences. For the future, we expect that we can remain competitive in acquiring funding and talent (PhD and other students, staff members). Important here is our embedding in the Amsterdam research environment (with as key partners UvA Physics and Astronomy, AMOLF and ARCNL, and also VUmc, AMC, etc.). The new building, with modern research facilities, which is currently being planned and which will become available within several years will surely contribute.

B.2.6 SWOT analysis

Strengths

- The greatest strength of LaserLaB is its excellent & productive staff.
- LaserLaB is very well embedded in the Amsterdam research environment. Groups at UvA, VUmc and AMC participate in LaserLaB; LaserLaB staff is also involved in ARCNL; key AMOLF staff have an appointment at VU/LaserLaB; and LaserLaB is involved in initiatives like Solardam.
- LaserLaB is a founding member of LASERLAB-Europe, and as such part of Joint Research Activities and the transnational user access programme.

- The research groups part of LaserLaB have, founded several spin-off companies. These companies are closely linked to the research groups and employ quite a few LaserLaB alumni.
- LaserLaB is a strong community of researchers from different disciplines with distinct research objectives, but all developing and using optical and laser technology. The institute is a centre of very broad expertise, from which individual researchers within the institute can make use, but also people from outside the institute.

Weaknesses

- LaserLaB is, for funding of its research, very strongly dependent on non-university funding, mostly from NWO / FOM and the EU, as discussed above.
- Over the last years, we have not exploited opportunities to apply for funding as an institute (e.g. NWO Gravitation, STW Perspective, ITN) and focused more (and very successfully) on obtaining individual funding.

Opportunities

- Although the far-reaching moving plans of IPA have been cancelled, there is still clear opportunity to further integrate the physics and astronomy community in Amsterdam, resulting in a physics hub in Amsterdam (including, besides UvA and VU Physics and Astronomy, AMOLF, ARCNL, Nikhef, and physicists in the university medical centres AMC & VUmc) of international scope, attractive for students, staff and visitors. One key prospect is that LaserLaB (Biophotonics & Medical Imaging) will get some lab space in the new imaging centre of VUmc.
- LaserLaB will move to a new building on the VU Zuidas campus. Plans are currently being made for a state-of-the-art building with excellent facilities, better and more attractive than our current situation.
- Research at LaserLaB is, because of its high quality and interdisciplinary character well prepared for the current and future funding landscape, including the restructured NWO, national Top Sector policies and the National Research Agenda (*Nationale Wetenschapsagenda, NWA).*

Threats

- As discussed above, the research funding situation is a continuous threat. Direct funding from the university is at a threateningly low level. At the same time, NWO is undergoing a major reorganization. It remains to be seen whether the past success of LaserLaB in obtaining NWO/FOM/STW funding in the last years can be maintained within the new organization.
- The increased administrative workload of the academic staff eats away time that could be spent on performing research, generating ideas and applying for funding.
- Now the move of (most of) LaserLaB / VU Physics and Astronomy to a unilocation with UvA at the Science Park Amsterdam will not take place and we will remain at our current *Zuidas* location, LaserLaB research will remain spatially separated from education, creating concerns of visibility of our research efforts to students, involvement of VU staff in the Physics and Astronomy programmes and extra travel time.

B.2.7 Relevant environmental factors and developments

- Changes in the Dutch funding landscape are taking place. For example, NWO is being reorganized, with more emphasis on interdisciplinary research. In addition, the National Research Agenda (NWA) is currently given form, with unknown new opportunities for funding (or shifts from current funding sources).
- Several decisions at the university level have important impact on LaserLaB. For example, in 2011 the Department of Chemistry and Pharmaceutical Sciences at VU decided to almost entirely focus on Pharmaceutical Sciences, basically stopping all activities within LaserLaB. Currently, a major reorgani-

zation is ongoing at the VUmc. As a consequence, the Physics and Medical Technology department in VUmc will be terminated as a separate entity.

- University funding for support (secretaries, technicians) has been decreasing, while management tasks have increased and demands from funding agencies and journals (i.e. with respect to data management, transparency etc.) Together with the increasing pressure to obtain external funding, this has substantially increased the workload of the academic staff.
- LaserLaB / VU Physics and Astronomy will remain at the VU *Zuidas* campus. Our current building will be demolished within several years. A new building is currently being planned, with facilities required for our research activities (e.g. low vibrations, good temperature control).

B.2.8 International position and benchmark

Within the Netherlands, the particular research focus of LaserLaB on the interactions of light with matter, spanning from research on atoms and molecules to the investigation of living cells and tissue and sustainable energy sources is rather unique. Within the European network of laser infrastructures we are part of, LASERLAB-Europe, several institutes exist with comparable scope, ambition and scale:

- LENS (European Laboratory for Non-linear Spectroscopy, Florence, Italy), an institute focusing on biophysics, atomic physics, photonics and reactivity. LENS is associated to the University of Florence.
- CUSBO (Center for Ultrafast Science and Biomedical Optics, Milan, Italy) is organizationally very similar to LaserLaB, as bundling of the laser-based research activities within the physics department of Politecnico of Milan.
- ICFO (Institute of Photonics Science, Barcelona, Spain) is somewhat larger than LaserLaB but has a similarly broad focus on applications in health, security, information and environment. ICFO is part of the Technical University of Catalonia (BarcelonaTech) and obtains direct funding from the government of Catalunya.
- LLC (Lund Laser Centre at Lund University, Sweden) has a similar, broad scope as LaserLaB and is integrated within Lund's Faculty of Science.

Another experimental physics centre within Europe with a similar broad scope (but a different focus) and comparable size and ambition is BIOTEC, the Biotechnology Centre of TU Dresden. BIOTEC focuses on interdisciplinary research and teaching in molecular bio-engineering.

Outside of Europe, institutes that can be compared to LaserLaB include:

- CPLC (Center for the Physics of Living Cells at the University of Illinois, Urbana Champaign) is an interdisciplinary research centre, NSF-funded, of comparable size to LaserLaB. Focus is more restricted to biological physics.
- MBI (Mechanobiology Institute, National University of Singapore) is a university-associated research institute with a very specific focus, the molecular basis of mechanotransduction in cells and tissues. The institute is interdisciplinary and has a size comparable to that LaserLaB.

B.3 PhD programme

The general policies set by the universities are described in Section .

B.3.1 Context, supervision and quality assurance

To assure the requirements on supervision and quality, the Department of Physics and Astronomy at VU has appointed a department-wide PhD monitor who acts as a confidentiality advisor for all PhD students in the department. Issues and/or problems that the PhD student can or does not want to discuss with the PhD supervisor can be discussed with this person. This advisor further informs all starting PhD students about the PhD system at the VU, the requirements to obtain a PhD and the right to receive education. In the third year, a short progress meeting of the PhD monitor with each PhD student is organized.

B.3.2 Courses for PhD candidates

The specific training programme at LaserLab comprises at least 30 EC and consists of a combination of the following elements:

- Laser safety course;
- Lab safety course;
- Courses on scientific integrity and research methodology;
- Individual training on advanced instrumentation;
- Courses from the MSc Physics and Astronomy;
- Presentation of a seminar at the group meeting, at least twice a year, with feedback from colleagues or supervisor;
- Attending 1 international and 1 national conference a year;
- Presentation at a national or international conference, including preparation with supervisor;
- Courses in transferable skill such as scientific writing or presentation and other career orientation courses, for which the VU offers a wide range of subjects. These trainings can be followed at either NWO or the VU training office.

Courses in the area of good conduct for academic practice/scientific integrity count as 2 EC, conference visits as 1 EC without a paper/presentation and as 2 EC with a paper/presentation. The courses on scientific integrity, research methodology, transferable skills and participation in conferences are mandatory. The Faculty of Science may grant an exemption covering all or parts of the PhD training programme of 30 EC. Exemptions for (parts of) the programme can be granted by the Dean when the PhD candidate has followed a similar course or (demonstrably) has acquired the necessary knowledge in a different way.

B.3.3 Selection and admission procedures

Most of the PhD positions at VU are funded by grants obtained by our researchers, and PhD candidates therefore apply to a research group and its PI. They follow a general hiring procedure that starts with an application letter and CV, continuing with an interview with the promotor and a small team of ad-hoc selected scientists from the department. A common part of the application is a seminar by the candidate. When the candidate is hired, the Dean appoints the relevant professor(s) and/or assistant professors as supervisor (promotor), second promotor or co-promotor, thereby establishing a formal responsibility.

B.3.4 Supervision of PhD candidates and guidance to the labour market

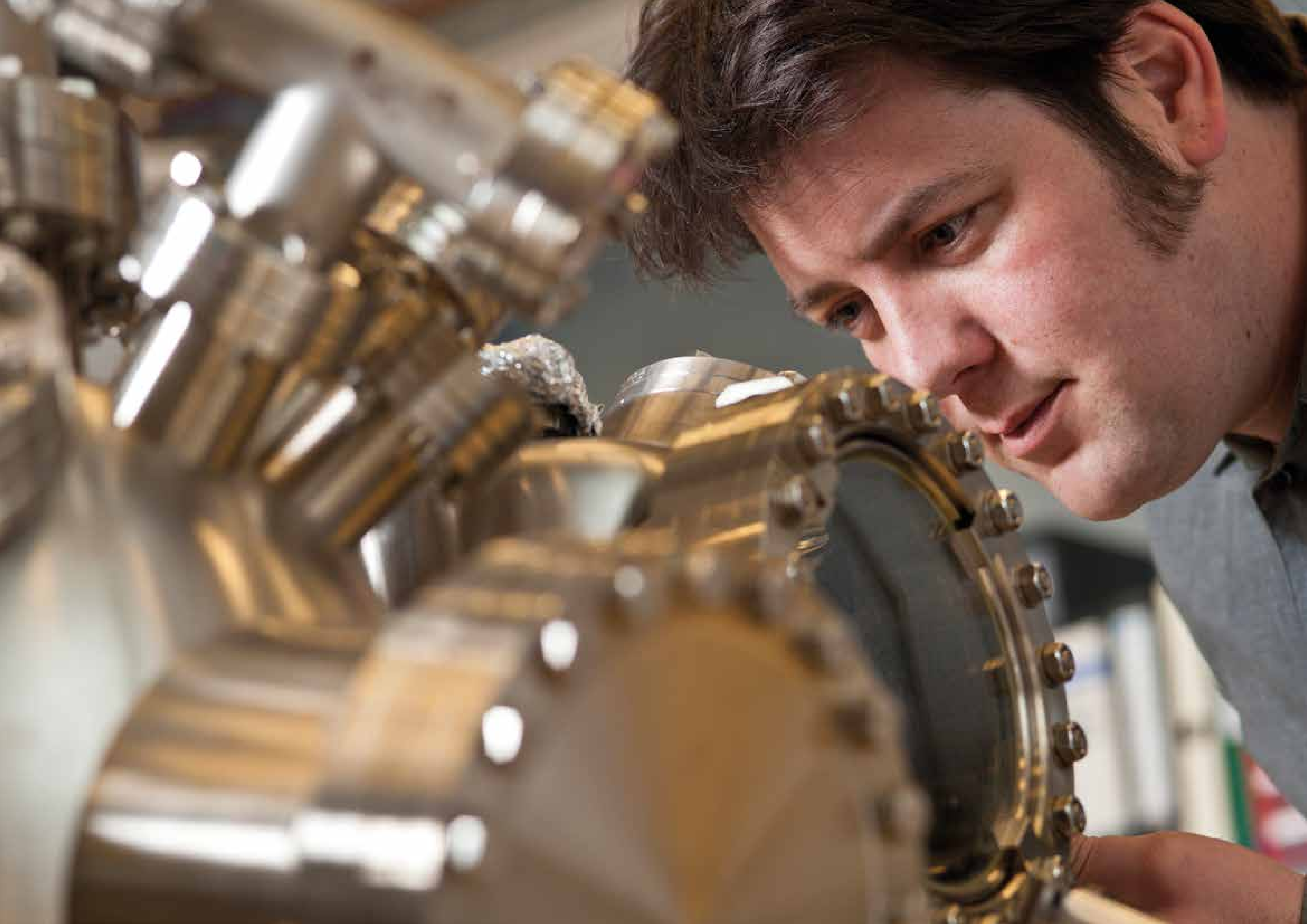
In the supervision plan, the frequency and form of the supervision by (co-)promotor(s) is described. General rule is that the candidate and a supervisor have at least one meeting per 2 weeks. Part of the supervision plan is an annual assessment of the progress of the candidate. At this moment, especially towards the end of the PhD, candidates are encouraged to follow courses and workshops to prepare them for a career inside or outside academia. Here the VU Training programmes for VU employees offers a wide range of possibilities.

B.3.5 Duration and success rates

In Appendix F.6.1, a table is presented of the time PhD students who started their contract from 2006-2012 (72 in total) take to graduate. 50 of these students have successfully graduated, 10 (20% of all graduates) of them within 4 years, 34 (68%) within 5 years and 44 (88%) within 6 years. 16 PhD students within the cohort (22% of all PhD students) have not graduated yet and 7 (9%) dropped out. We note that, at the VU, it takes several months between handing in the final manuscript of the thesis and the actual defence date (typically 4-6 months, including 1 month evaluation by the reading committee and a variable time depending on the availability of graduation time slots). Nevertheless, a substantial number of our students do not hand in their thesis manuscripts within their 4-year contract period. There are several reasons for this. First of all, most of the research performed within LaserLaB is of an experimental and often high-risk/high-gain nature and thus difficult to plan reliably. Second, there is a tendency both with the students themselves (and in particular the ones interested to pursue an academic career) and their supervisors to stretch the final stage of the PhD, in order to get the final parts of the research project finished and published. Third, it is our experience, in particular with respect to high-impact studies, that the time it takes to get manuscripts published has increased. Finally, there are situations where the actual writing of the thesis by the PhD student takes longer than anticipated, in particular in situations where the student has already taken up another job. The point of PhD duration has our attention, but we also note that it is important to keep the standards of a PhD from LaserLaB high.

B.3.6 Exit numbers to various sectors

A total number of 33 PhD students have graduated from LaserLaB from 2010-2016. The pie chart in Appendix F.6.1 presents an overview of the first jobs the alumni obtained after graduating. Our general impression is that the alumni fare well and find jobs quickly within and outside academia. At least 44% of alumni have found postdoc positions in prestigious international universities and institutes (including Stanford, Harvard, ETH Zurich, UC San Diego, and Max Planck CBG Dresden). One has found a staff position at a university (Yazd University, Iran). A substantial fraction (at least 33%) of the graduates decides to leave academia and join industry (including ASML, Akzo Nobel, Shell and LaserLaB spin-offs LUMICKS and Optics11). Several (7%) have joined (semi)government research institutes like TNO (applied research) and CBS (national statistics institute).



C. UvA Van der Waals-Zeeman Institute (WZI)

C.1 Introduction

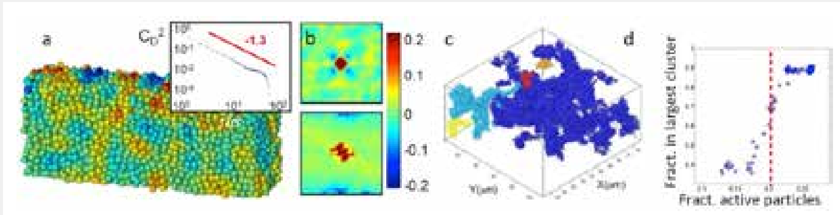
The van der Waals-Zeeman Institute (WZI) is one of three divisions of the IoP; it merged with the other two physics institutes to form the IoP in 2010. Amsterdam has a long-standing tradition for excellent experiments in physics, and this tradition is perpetuated in the research of the WZI. The years 2010-2016 have seen profound changes in the WZI. The institute was significantly rejuvenated by new hires and at the same time grew considerably in size. A dedicated experimental physics track was created in the MSc programme, Advanced Matter and Energy Physics (AMEP), which now delivers a significant part of the PhD students to the WZI. Among the most important developments are:

- 2009: National Sector Plan for Physics and Chemistry was approved, which included structural funding for the Soft matter and Quantum Gases clusters.
- 2010: The WZI becomes part of the IoP.
- 2011: Hiring of Shahidzadeh.
- 2012: Soft Matter becomes a Research Priority Area of the WZI.
- 2013: Van Heumen and Newell-Dohnalová join the Hard Condensed Matter group, the latter with a MacGillavry Fellowship. Schreck joins the Quantum Gases group supported by national Sector Plan funding, bringing in an ERC Consolidator Grant. Faculty Research Priority Area (RPA) Quantum Matter & Quantum Information becomes a University RPA.
- 2014: Launch of ARCNL; Schall wins an NWO Vici grant.
- 2015: Schreck wins an NWO Vici grant; QuSoft proposal from the Research

Highlight

Soft Matter

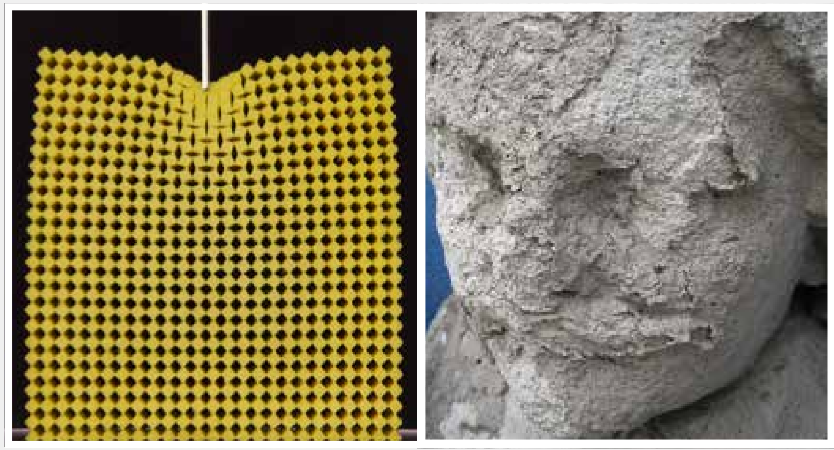
The Soft Matter group studies the dynamics of complex fluids and solids such as surfactant polymers, colloidal suspensions, porous disordered solids and meta-materials. We work on a plethora of soft matter systems and strive to combine fundamental research with potential for technological innovation, as exemplified by large amount of industrial collaborations.



Diverging strain correlations in a colloidal glass subjected to deformation. (a) Reconstructed internal shear strain field. Inset: long-range correlations of non-affine displacements. (b) Internal strain correlations before (top) and after (bottom) shear banding. Symmetry demarcates a dynamic first-order transition. (c,d) Percolating cluster of highly active particles.

- Tremendous progress has been made in our understanding of out-of-equilibrium and driven systems using well-selected soft matter systems as models. This has led to an invited Rev.Mod.Phys. paper on yield stress, the first experimental determinations of both the free energy of glassy systems, their density of states and direct visualizations of internal strains and stresses (Fig. 1a).

- We also demonstrated the universality of this dynamic critical phenomenon with leading groups in the US using a wide range of systems spanning 14 decades in length scale, from deformed nanocrystals to earthquakes. The generality of earthquake-type dynamics in complex systems is striking: glasses also showed Gutenberg-Richter type behaviour.
- New powerful approaches in metamaterials allow to tailor their spectacular properties through design and digital fabrication techniques. We used this to generalize geometrical and topological concepts that were initially developed in quantum physics.
- A novel collaboration was developed with the conservation and restoration facility of the Rijksmuseum: the newly founded Netherlands Institute for Conservation in the Arts and Sciences (NICAS) that is a collaboration between the exact sciences and humanities.



'Man-made' and 'Nature-made' porous materials; the first have exceptional non-linear mechanical properties, the second are prone to degradation by salt or ice crystallization.

Priority Area QM&QI wins UvA funding, with a number of WZI groups affiliated.
- 2016: Gerritsma joins WZI with an NWO Vidi and ERC Starting Grant.
- 2017: Hiring of Coulais (Soft Matter group).

As this list illustrates, there has been a significant strengthening and rejuvenation of all research teams of the WZI during the past couple of years. The growth of the institute was made possible by many successful individual grant applications and external developments such as the Sector Plan and the MacGillavry Fellowship programme, as well as the Research Priority Area policy of the university and faculty.

C.2 Research description

C.2.1 Organization, composition and financing

The WZI is one of the three divisions of the IoP and performs small-scale experimental research in the areas of Hard Condensed Matter, Soft Matter, and Quantum Gases & Quantum Information. These are the three 'pillars' that support the WZI.
The IoP is led by a directorate / management team consisting of the heads of the three divisions and the institute manager. Daniel Bonn is head of the WZI since 2012. A number of major cost factors for the experimental research at the WZI, such as technical staff costs, workshop support in the Faculty's Technology Center and purchasing of cryogenic liquids (nitrogen, helium) are not split up and distributed on the research group level. This policy ensures the necessary continuity in the technical support for the institute and helps maintain a culture of solidarity.
The table below lists the permanent staff members of WZI. Special positions (professors by special appointment, part-time staff) are marked in italics.

Group	**WZI members** *(Part-time appointments and professors by special appointment in italic)*	Connects to
Hard Condensed Matter: quantum matter	Golden, de Visser, van Heumen, Huang, Planken (ARCNL), *Frenken* (ARCNL), Dürr (SIMES/SLAC)	ITFA Theoretical Condensed Matter Physics, QuSoft, ARCNL
Soft Condensed Matter	Bonn, Schall, Sprik, Shahidzadeh, Coulais, *M. Bonn* (MPIP Mainz), *Velikov* (Unilever), *de Bruin* (NFI)	ITFA Soft Matter group/ Soft Matter RPA/ IvI/ HIMS Soft Matter groups, VU Physics of Living Systems
Hard (and Soft) Condensed Matter: Optoelectronic Materials	Gregorkiewicz, Schall, Dohnalová-Newell, *Polman* (AMOLF), *Sinke* (ECN)	Solardam, HIMS, AMOLF, VU Physics of Energy/Biophysics
Quantum Gases and Quantum Information (QG&QI)	van Druten, Gerritsma, van Linden van den Heuvell, Schreck, Spreeuw, *Walraven (emeritus)*, Shlyapnikov (emeritus, LPTMS Paris), *Koenderink* (AMOLF), *Noordam* (ASML)	QuSoft /QMQI RPA, VU AMO group

External funding

The Hard Condensed Matter group has earned over 5.3M€ in external grant funding in the evaluation period, distributed 45:55 between the Quantum Matter and Optoelectronic Materials activities. All group leaders are/have been PIs of successful applications, with major grants (>650k€) being organized, written and led by both Golden (FOM TI programme) and Gregorkiewicz (3 x STW). Van Heumen played a major role in the recent successful FOM programme proposal Strange Metals (bringing >1M€ to IoP-WZI). The funding sources are, in order of decreasing contribution: FOM, STW, NWO, international and local (Solardam, QuSoft, ACE Venture Lab, MacGillavry fellowship). Dohnalová won the 2012 Amsterdam Science and Innovation Award, the 2013 FOM Minerva prize and was awarded a MacGillavry Fellowship in the same year, winning a FOM *projectruimte* grant (400k€) in 2016. Hard Condensed Matter was home to 46 staff, postdoc & PhD researchers over the review period and currently has 22 members, 2/3^{rds} being grant-funded.

The Soft Matter group has earned over 7.9 M€; remarkable external funding obtained include: NWO Vici grant (Schall), IPP programme grant Michelin/SKF headed by Bonn, IPP programme grant with Unilever (Schall/Bonn), several FOM/Shell grants (Sprik/Bonn), EU JPI-cultural heritage grant (Shahidzadeh), STW project grants with the Netherlands Forensic Institute (NFI) and several other grants that typically pay for a PhD student or a postdoc. The total size of the group is now ~25 people, mainly paid from grants.

The Quantum Gases & Quantum Information group has earned over 8.6 M€ in the evaluation period; remarkable grants are ERC Consolidator Grant (Schreck), NWO Vici grant (Schreck), ERC Starting Grant (Gerritsma), NWO Vidi grant (Gerritsma), FOM programme together with TU/e (Spreeuw, van Druten, van Linden van den Heuvell), 2020 FET ProActive project, Marie-Curie ITN, 2 FOM projectruimte grants (Spreeuw), NWO Veni (Pasquiou, k€ 250). The total size of the group is now more than 25 people, mainly paid from grants.

C.2.2 Strategy and targets

The **targets** of the WZI are:

- Achieve **research excellence** across a varied programme of important themes in experimental physics, enabled by a combination of external funding success, very good experimental facilities and core critical mass in the permanent research staff.
- Cover a **balance of research areas** from strongly fundamental to work with a long-term applications horizon to full-value partnerships with the private sector (PPP's). This spectrum enables strong partnerships with theory (e.g. ITFA), with NWO institutes and with market parties, all driven by the intrinsic passion of the PIs at the WZI for their research subject matter.
- Increase the **international visibility and reputation** of the WZI, also as part of IoP and the wider Amsterdam physics landscape, and play a **constructive and leadership role** in the local, national and international physics communities and as ambassadors for physics to the general public.
- Identify, initiate and grow **connections** with VU Physics and Astronomy and with the para-university institutes located in the Science Park Amsterdam, and to be inspired by and take advantage of the full breadth of the Science faculty in whose building we are housed.
- Inspire and enable new generations of students, PhD researchers and post-docs to reach their **full potential** while learning and doing research with us, so they can move on with confidence and success to their next career stage outside or inside the science domain.

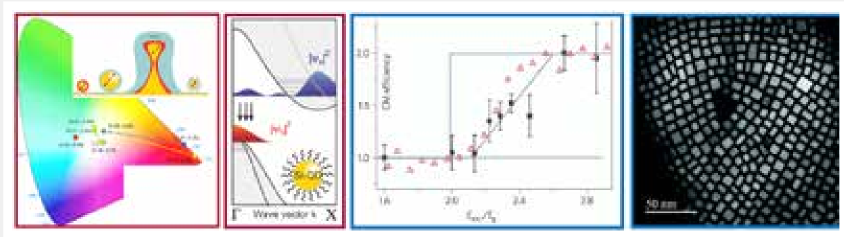
The **strategy** of the WZI to achieve these targets in the period 2010-2106 included successful applications for external grant funding, the Sector Plan boost of the direct university funding for physics and highly effective operation within the IoP umbrella inside the faculty and university (100% of the WZI's programme is within a faculty Research Priority Area and two-thirds in one of the university's 20 RPAs).

Highlight

Hard Condensed Matter

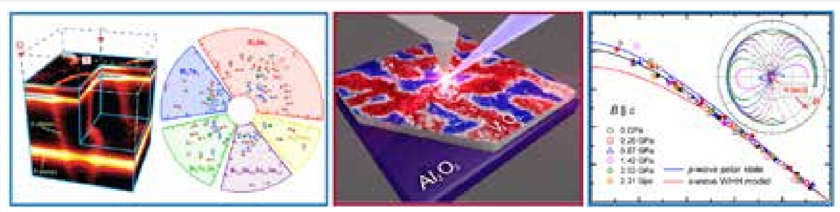
The Hard Condensed Matter group works on the electronic, magnetic and optoelectronic properties of novel solid-state systems, involving strongly fundamental work on the emergent properties of correlated electron materials and novel superconductors, as well as research on novel semiconductor nanocrystals (perovskites) for potential use in (nano)photovoltaics.

- We showed how Si nanocrystals can be used in light and energy management and increased effective lifetime of 'hot' carriers by (at least) 3 orders of magnitude, opening the door to spectral shapers for photovoltaic cells.



From left to right: Engineering the oxide shell of Si nanocrystals places their emission right in the daylight/white-light centre of the colour gamut (Light: Science & Applications, 2017, patent application Spectris-dot B.V.); Surface modification boosts direct band gap recombination in Si quantum dots (Light: Science & Applications, 2013); Si nanocrystals are proven to boost carrier multiplication efficiency (Nature Nanotech., 2011) and solution processed inorganic perovskite nanocrystals are proven stable and optically fully tunable (Nanoscale, 2017).

- Single-crystalline 3D topological insulators have been grown and investigated using (magneto)transport and angle resolved photoemission. We have solved the disagreement between QO and ARPES measurements of topological surface states in Bi-based systems.
- Upper critical field experiments on M-doped Bi_2Se_3 (M=Cu,Sr) have built a very strong case for topological superconductivity.
- The impact of dimensionality and ultrafast switching on the metal-insulator transition of complex oxides has been uncovered, and the first nanoscale visualization provided of the correlated metal-insulator-transition in V_2O_3, uncovering complex textures between the coexisting metallic and insulating patches.



From left to right: ARPES uncovers the 4f-5d hybridization in the proposed topological Kondo insulator, SmB_6 (PRX, 2013), and explains why QO (blue symbols) and ARPES (red symbols) disagree so strongly on the energy of the Dirac point in topological insulator surface states (PRX, 2017); Nano-IR imaging reveals nano-textured phase co-existence in the correlated insulator V_2O_3 (Nature Physics, 2017); Pressure dependence of the upper critical field of Cu-doped Bi_2Se_3 argues for bulk topological superconductivity (PRL, 2012). The inset shows the two-fold (in plane) symmetry of H_{c2} for nematic superconductivity in Sr-Bi_2Se_3, a clear sign of odd-parity, spin-triplet Cooper pairs (Scientific Reports, 2016).

The aim was to reach **supercritical staff size and parity in all three research pillars**, also resulting in a **good age distribution**. Targeted actions were taken to improve the experimental infrastructure, providing leverage to grant proposals and opening new avenues for collaboration, both within WZI and beyond.

The scientific relevance of our research is underpinned by the grand challenges we work on. Examples of such challenges that inspire the research at the WZI and thus clearly define our research ambitions are:

- **Model systems.** The glass transition is perhaps the largest unsolved problem in condensed matter physics. Can we use model systems to understand the relation between the microscopic disorder and dynamics and the macroscopic mechanical properties?
- **Emergent quantum matter.** How can we understand the emergent properties of correlated electron systems such as complex oxides and intermetallic quantum critical matter, systems displaying topological protection and novel superconductors (high Tc, spin-triplet, topological)?
- **New materials.** Can new materials such as perovskites and transition metal dichalcogenides revolutionize the silicon-dominated world of photovoltaics/optoelectronics?
- **Realizing new, many-body regimes.** Can the creation and control of novel types of interactions between particles in quantum gases allow us to access unexplored many-body regimes, for example in lattice-spin models?
- **Continuous atom laser.** Can a continuous source of quantum gas (atom laser) be developed, which would have a major impact on the development of the next generation of atomic clocks?
- **Understanding friction.** Friction is responsible for 30% of the world energy consumption, but a microscopic understanding is still lacking. Can we understand contact mechanics and develop a complete understanding of what controls friction?

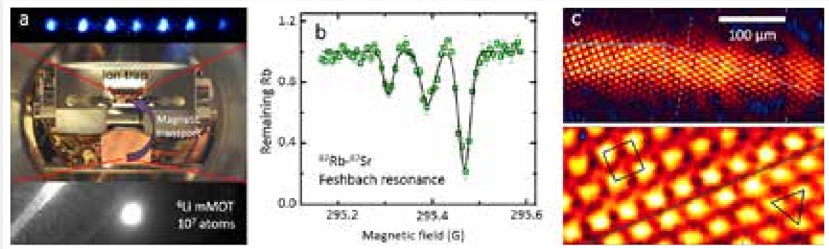
These grand challenges not only flow from the research interests and match the skills of our PIs, but also offer ideal connectivity for a community of ‘users’ of our science that spans from young **students** getting inspired and challenged to **theory colleagues** in Amsterdam and further afield. From **strategic research institutions** such as ARCNL, NFI, TNO & AMOLF to **influential market actors**

Highlight

Quantum Gases and Quantum Information

The Quantum Gases & Quantum Information group studies quantum few and many-body physics using ultracold atoms, molecules and ions. We are creating and controlling novel types of interactions between the particles, such as long-range interactions between Rydberg atoms or between atoms and ions to access unexplored many-body regimes. We also study the development of a continuous source of quantum gas, which would have a major impact on the development of the next generation of atomic clocks.

- We measured quantum chemistry in Yb^+-Li, which is the most promising ion-atom mixture to study quantum dynamics in, due to its large mass ratio.
- We observed for the first time magnetic Feshbach resonances in mixtures containing a closed-shell atom (Rb-Sr). These resonances should allow magnetoassociation of Rb and Sr atoms into weakly bound RbSr molecules.
- We achieved trapping of atoms in microtrap lattices, interfacing square and triangular, on a magnetic-film atom chip, and observed collective light scattering in these microtraps.



a) Setup for studying Yb^+ Li mixtures. A crystal of ions is trapped in a Paul trap (top) while a cloud of cold atoms is prepared below. The atoms are transported to the ions by magnetic fields. b) Loss of Rb atoms indicates magnetic Feshbach resonances between Sr and Rb. c) Magnetic lattices on an atom chip hold clouds of Rb atoms. A boundary between lattices of different geometries has been implemented.

(Shell, Unilever, Michelin, SKF, Akzo Nobel) with whom public-private partnerships form a natural conduit for our know-how to help create wealth, jobs and solve societal problems.

The WZI’s researchers have recently founded two spin-off companies. These are the **first spin-offs in the institute’s history** (or that of her fore-runners), and show an evolution of our understanding of our role also outside academia.
The aims of increasing visibility and reputation and growing interactions with (local) partners are mutually enhancing. Given the stable launch-pad of super-critical staffing and healthy finances, a clear strategy of **forging new links** could be pursued. Looking across the WZI’s three research pillars, apart from within IoP, we are now meaningfully connected to VU Physics and Astronomy, ARCNL, QuSoft, AMOLF, Solardam and the Informatics (IvI) and Molecular Sciences (HIMS)

institutes of VU. Looking forward, the strengthening and deepening of these links, and taking inspiration from WZI colleagues already connected, to establish new links are clear points of focus for the coming period.

Even though the unilocation plans for IoP and VU physics will not be realised, the **bundling of forces** remains a strategy with which we will enhance the visibility and perception of the WZI, both in a national and international context. The high local concentration of physics R&D, and the short distances over which national Dutch collaborations operate are both good starting points for further growth in this area. In concrete terms, WZI will steer towards a **strengthening of ties, joint PhD students and grants, joint visiting professorships, the exchange of guests and seminar information**.

C.2.3 Performance indicators

The standard performance indicators are (top) publications and citation scores of individual researchers. Additional essential indicators of quality are the number of invitations to speak at workshops and conferences, and to lecture at schools and give colloquia.

Another important indicator for assessing the performance of the institute is the number and quality of successful grant applications. These give (peer-reviewed) testimony of the potential and quality of the applicants, often before they prove themselves in publication summary data. This is particularly true for young PIs starting up new experimental activities, where the lead time, in building the apparatus before the actual experiments are performed, can be long. Given that the WZI has recently successfully attracted a number of young group leaders, we believe that an important indicator for assessing the performance of these subgroups is formed by their successful grant applications. This is particularly true for the QG&QI group, where two new group leaders were appointed who started no less than 4 new experimental setups within the review period, amounting to more than half of the QG&QI effort.

Setting up overarching research themes and international collaborations are strong prerequisites for performing internationally competitive research. Good performance indicators for these are collaborative grants within and outside of the University as well as joint publications with (international) collaborators. Other important performance indicators are the number of PhD theses, individual and collaborative grants obtained, involvement in (inter)national collaborations, prizes and distinctions, editorships, prestigious memberships, etc.
The possibility and ability to attract new talent as evidenced by the number of applications for PhD, postdoc and staff openings is also a good indicator of the international standing of the institute. Regarding societal relevance, indicators are (i) PhD graduates finding employment in industry or government, (ii) successful outreach activities and (iii) valorisation/start-up activities.

C.2.4 Results achieved

Scientific excellence
The output of published scientific work has been excellent over the last period. The total number of peer-reviewed publications within the evaluation period (2010-2016) was 270, with one in five of these being in high-impact journals (Science, Nature family, PRL and journals with impact factors higher than PRL such as PNAS and PRX), as detailed in the appendix. The bibliometric analysis confirms the high impact of our research work. The share of the WZI's top-10% (top-1%) publications in upper-tier journals is more than three times (six times) the world average and even our publications in journals with low impact factors have high average impact. Some of the successes underlying this impact feature in 'research highlight' boxes, below. Many of the highlight results from WZI involve (inter)national collaborations, as the joint authorships attest to.

Our research programme (and the resulting output) covers a broad spectrum from fundamental through to directly applicable science, having impact in fields beyond physics, such as materials science, chemistry and engineering (see the separate bibliometric report). Publication excellence is across the board within WZI, though we note that the QG&QI pillar has some catch-up work to do, resulting from the restructuring of the research staff. The successful attraction of Schreck and Gerritsma has offset the retirements of Walraven and Shlyapnikov, although the intensive experiment build-up activities of these new PIs in the evaluation period has impacted publication numbers in this corner. The grant successes in the QG&QI group show the credibility of their plans, and now that the new experiments are coming online, the (top) publications will follow.

The healthy age balance of the PIs in the WZI reflects a good balance between experienced researchers (with high H factors) and young, promising group leaders (with strongly growing H factors) bringing in refreshing ideas while assuring continuity on the broad brush-stroke level. The excellence of the research and the global interest in it is also underlined by the many invitations to speak at conferences (219 in the evaluation period) and colloquia, and we do our share of successful conference organization (19 in the evaluation period).
The WZI PIs have been very successful both in collaborative research grants – in the Science Faculty (RPAs), in the University (RPAs), in Amsterdam (AAA, QuSoft, NICAS), in the Netherlands (FOM programmes: open competition & IPPs; STW: open technology programmes [like IPP] and managed programmes; industrial collaborations) and beyond – and in winning personal grants (NWO Veni/Vidi/Vici, ERC, Marie Curie). All of these are the result of highly competitive processes, underscoring our quality, originality and openness to collaboration and co-operation. This great success in external funding is across the board in terms of the WZI's pillars, and across the board in terms of our spectrum from highly fundamental research programmes via explorative research closer to possible application to direct collaborations with industrial partners.

Societal relevance
The WZI has acted as a good employer/supervisor for her PhD students and as a good career booster for her postdocs. We have done very well in PhD graduations, with 67 people leaving us with a PhD degree in the evaluation period. These graduates are successful in the job market, i.e., in high-tech companies, industry and other promising sectors but also in (tenure track) staff positions. The fact that we know where the vast majority have gone to, attests to the good community feeling in the WZI and the commitment we have to our PhD students and postdocs.

With a view to our stakeholders in the broadest sense – our fellow citizens in Amsterdam and the Netherlands – the WZI has succeeded in awakening great interest in the research work, and been very active in outreach. Again, the spectrum runs from fundamental 'wonder in science' activities (quantum physics, superconductivity, levitation, walking on water, blood splats and even topology and quantum computers) to research results that enjoy direct public interest, such as the work on sand castles and friction in the context of the Egyptian pyramids. The latter type of research enjoyed great national and international press interest. Outlets for outreach have varied from Sunday demo-lectures at the Amsterdam Science Museum (NEMO), school visits (usually with demos) and open days to more formal and intensive activities such as the Universiteit van Nederland, National Research Agenda (NWA), Gala van de Wetenschap & SPUI25. If people are looking for hands-on demos to demonstrate fascinating physics on a table-top scale then we find they often knock at our door and we see it as part of our mission to help.

Finally, we turn to the important theme of serving society through the use of or results outside science and the valorisation of our research. In the evaluation period, the WZI has been partner in 21 public-private-partnerships, 15 in Soft Matter and 9 in Hard Condensed Matter. Our (semi) private partners include major multinationals (e.g. Shell, Unilever, SKF, ASML, Michelin etc.), mid-sized companies (e.g. NXP, erstwhile Helianthos, erstwhile MEMC), small companies (e.g. a number of these have joined in the Joint Solar Programme III in which the WZI is involved) and organisations such as the Rijksmuseum, Energy research Centre of the Netherlands (ECN), Dutch Forensics Institute (NFI) and the Netherlands Organization for Applied Scientific Research (TNO). These partnerships generate research income, but also anchor the activities of the WZI in society, and in the Dutch and global economy. Last but certainly not least, WZI is very happy to employ PIs who set up start-up companies. After a century with no such activities, this evaluation period saw the foundation of Spectris-dot B.V. (Katerina Dohnalová-Newell, HCM) and GreenA (Daniel Bonn, SM), and we see this as an important new chapter in our history.

A relevant opportunity in this respect is the launch in 2016 of the *Amsterdam Physics Research and Innovation Lab* (APRIL). APRIL is part of the new 'IXAnext' program by the Innovation Exchange Amsterdam (IXA), the joint Technology Transfer Offices of (a.o.) UvA and VU, aimed at stimulating valorisation initiatives by the Amsterdam knowledge institutes. IXAnext received substantial financial support by the Municipality of Amsterdam. One of the pillars in APRIL is a 'Physics on Demand' service, aimed at the acquisition of applied contract research of short duration (weeks to months) with small and medium businesses. For WZI, these projects can serve as a stepping stone towards larger and longer projects for which external funding from NWO, STW etc. can be acquired. The full IXAnext program involves a municipality subsidy of 7M€ for five years (with in kind contributions by the knowledge institutions amounting to over 30M€); APRIL obtains about one third of this.

C.2.5 Own assessment of quality, relevance and viability

The WZI is doing well, as is evident from the growing staff, the high amount of external funding acquired, including many prestigious personal grants and the scientific output. All three pillars enjoy international renown, and all bundle a critical mass of academic staff with a healthy spread of seniority. There is an important 'family feeling' in the WZI, visible in the solidarity between the different pillars of the institute: we have joint technicians, shared costs for TC (workshop services), joint (efforts preparing for) grant proposals, we keep a mentoring eye on each other's PhD researchers, there is a weekly staff lunch and many more joint initiatives, e.g. for outreach. Joint (IoP-wide) colloquia are successful and many good international speakers can be attracted. Due to the WZI being the launch-pad of the MSc track Advanced Matter & Energy Physics (AMEP), our visibility to students has greatly improved, and more than half of the WZI's PhD students come from our MSc track: at the beginning of the evaluation period, this was ~10-20%. For the future, we expect that we can remain competitive in acquiring funding and talent (PhD and other students, staff members). Important here is to continue to intensify and profit from our embedding in the Amsterdam research environment (with as key partners VU Physics and Astronomy, AMOLF and ARCNL).

As is the case for all three pillars of the WZI, the **Hard Condensed Matter (HCM) group** is thriving and growing in international visibility. Its strong funding base, excellent lab infrastructure and well-chosen, modern themes in solid-state and materials physics attract a strong team of international young researchers and we are very successful in the competition for the best experimental Master's students. HCM co-leads the UvA's new research priority area Quantum Matter & Quantum Information, an important step toward QuSoft, in which also theory and the QG&QI groups are players from IoP. Collaboration (leading to jointly supervised MSc and PhD students and joint papers) with IoP's CMT group is on the up, and we have concrete and growing links with ARCNL (near field optics), AMOLF (nanophotovoltaics), VU Physics and Astronomy (nanophotonics & semiconductor nanostructures for natural and artificial photosynthesis) and QuSoft (quantum information for quantum matter). HCM's two new staff recruits bring new energy and directions to the group, and help maintain a good balance between fundamental and more applied research approaches. Successful replacement for Tom Gregorkiewicz, who will retire soon, is a key objective; an open and international recruitment process is in the start-up phase.

The **Soft Matter (SM) group** is recognized as being internationally leading; it is a large, lively group with a strong publication output, many international visitors, excellent experimental facilities and very good funding. The recent arrival of Corentin Coulais brings a number of interesting new themes (metamaterials, driven systems) into the group, and most of the SM staff already have collaborations with him, illustrating the team spirit in the group. However, many possible collaborations are running but are still underdeveloped, e.g. with UvA chemistry, informatics or biology but also with other institutes such as AMOLF, ARCNL and the VU. Making more of the Soft Matter Research Priority Area is high on the list of priorities in this respect.

The WZI successfully rejuvenated the **Quantum Gases & Quantum Information (QG&QI) group** by hiring a tenure-track PI and a new full professor. The group enjoys strong national and European funding (ERC, NWO Veni, Vidi, Vici, FOM programme, etc.) and is highly attractive for international Master's and PhD students. The new experimental setups have recently become operational. They provide us with worldwide unique physical systems (e.g. Rb-Sr, Rydberg atoms and nanolattices on atom chips, Li-Yb^+), giving us an excellent perspective for high-impact work. Our work is stirring interest in the international community, resulting in fruitful collaborations with theorists and experimentalists abroad, as can be seen in joint publications, grant applications and participation in European networks.

C.2.6 Relevant environmental factors and developments

The WZI is naturally disappointed that the merger between IoP, API and the VU Physics and Astronomy didn't come about as was hoped. This does not diminish in any way the physics-based positives of our proximity, our close relationship in teaching and research in Amsterdam, and our shared commitment to harvest as much of the added value from working together as possible. For example enhanced link-ups between Soft Matter, VU Physics of Living Systems and AMOLF makes just as much sense now as it did a year ago. The same goes for the QG&QI and the AMO activities at the two campuses.

For the HCM group, the relatively recent arrival of the ARCNL institute at Science Park has led to first joint projects and joint PhD students. More links are possible, such as in lensless XUV imaging and electron-related processes in EUV resists. QuSoft and the broader QM&QI priority area offer great opportunities for cross-fertilization between approaches from quantum information yielding progress in understanding complex quantum matter.

Over the past years, all three pillars of the WZI have been reinforced with new and young staff; the age distribution in the institute is becoming more balanced. This has given new *elan* everywhere that we should now capitalize on, especially for attracting good students, postdocs and possibly staff; the upcoming retirement of Gregorkiewicz is something that poses strategic questions for the HCM group. BSc and MSc student numbers have been going up steadily and quite significantly over the evaluation period, and a significant fraction of the PhD students now come out of our own MSc programme. Demographically, it is expected that the number of young people will decrease; our MSc track AMEP oscillates around the critical/subcritical borderline, which requires extra attention. The number of starting BSc students is good, but many of them stop within the first year; this is probably the main challenge for getting more students into the different MSc tracks, together with attracting more foreign talent.

C.2.7 SWOT analysis

Strengths:

- Successful attraction of excellent young group leaders (Shahidzadeh, Van Heumen, Schreck, Gerritsma, Coulais, Newell-Dohnalová).
- All groups have become supercritical in the past years.
- Very good facilities/enough space.
- Outstanding successes in prestigious funding schemes (ERC, NWO, FOM).
- Excellent output, except for the QG&QI group. Its recent rejuvenation however now starts to bear fruit.
- Student numbers are increasing due to increasing popularity and overall increase in numbers.
- Lively group meetings, good atmosphere, many visitors, fruitful international exchanges.
- Large valorisation potential; large number of public-private partnerships, involvement in start-ups, industrial visitors and part-time professors.
- All research activities of the WZI connect to many other disciplines via the faculty and (for HCM and QG&QI) UvA research priority areas.

Weaknesses:

- We are not sufficiently well-known, seen as world-leading or visible yet; this makes us less effective in attracting talent than our performance warrants.
- We are not yet fully exploiting collaborations within the Science Park (even with AMOLF).
- There aren't enough interesting seminars at the WZI.
- The QG&QI group has achieved a relatively low publication rate in recent years; the outlook is much better with new experimental setups coming online now.
- No-go on the plans for VU physics moving in has not improved the credibility of UvA.

Opportunities:

- Our excellent research environment allows us to become worldwide leading.
- We are housed in the same building with other disciplines, in close vicinity of AMOLF/ARCNL.
- There is much room for exploring further opportunities for collaboration QuSoft, ITFA, NICAS, VU.
- Close collaborations of the SM and HCM groups with industries facilitates funding.
- Succession of Gregorkiewicz by a new staff member in Hard Condensed Matter.

Threats:

- Maintaining group sizes and maintaining the current funding level may prove challenging.
- The reorganization of NWO (leading to the dissolution of FOM and STW) could affect the funding situation.

C.2.8 International position and benchmark

Small-scale experimental physics (as opposed to particle physics) such as is done at the WZI is rather expensive and therefore internationally mostly done in Europe, Japan and the US. However, in recent years, many countries such as China, Korea and India have invested heavily into experimental physics, and the scientific landscape is changing rather rapidly. Still, the benchmark institutes are for the larger part in the US and Europe.

The WZI is based on three pillars that cover different areas of physics; in the past this has proven to be a robust way of ensuring the continuity of the experimental institute; in spite of changes in 'fashion', retirements and the shift in funding focus towards more collaboration with industry, the WZI is still growing in terms of personnel, publications and budget. There is a substantial amount of cross-fertilization with other parts of the IoP but also with our colleagues from the VU, neighbouring experimental physics institutes AMOLF and ARCNL, as well as with the many other disciplines and institutes present at the Faculty of Science or at the Science Park.

Some relevant benchmark institutions are:

- The Departement de Physique de l'Ecole Normale Superieure de Paris: while substantially larger than the WZI, it has the same research goals and hence the same three pillars as the WZI, in addition to theoretical physics.
- ETH Zurich is also much larger than the WZI, but its infrastructure and facilities are similar, allowing to do world-class experimental physics research.
- The Experimental Condensed Matter Physics at Cornell University has a good mapping for HCM and SM, but less so for atomic/laser physics.
- UCL physics has a large department containing condensed matter (CMMP, 25 staff members, without emeriti and honorary), atomic physics (AMOPP, 19 staff), and biophysics (BioP, 13 staff), rather than soft matter
- Stewart Blusson Quantum Matter Institute, UBC, Vancouver combines both experiment and theory, and also involves chemistry. It lacks Soft Matter. The institute recently received a 60MCan$ grant.
- Condensed matter physics at Oxford University, UK, covers HCM/QMat and semiconductors, but biophysics rather than soft matter.
- ESPCI in Paris, France, hosts some of the most distinguished and creative colleagues in the field of soft matter, optics and acoustics.
- KTH Stockholm is a high-class technical institute, with excellent facilities and leading researchers.
- JILA a joint physics institute of the University of Colorado at Boulder and the National Institute of Standards and Technology. It is significantly larger than the WZI within the field of QG&QI.
- MIT-Harvard Centre for Ultracold Atoms, National Science Foundation Physics Frontier Center; again this is much larger than the WZI in the QG&QI field.
- The Max-Planck-Institute for Quantum Optics is perhaps the largest effort in quantum optics.
- The European Laboratory for Non-Linear Spectroscopy (LENS) is similar in size to the combined UvA and VU efforts in this field.
- The Joint Quantum Institute of the Department of Physics of the University of Maryland (UMD), National Institute of Standards and Technology (NIST) and the Laboratory for Physical Sciences (LPS) is a somewhat smaller but nonetheless competitive effort in quantum gases.
- The Institute for Quantum Optics and Quantum Information of the Austrian Academy of Science, together with University of Innsbruck and Vienna University, is an important collaboration on QG&QI.

Our Unique Selling Point, compared to these other institutes, is the combination of (i) the high individual quality of the researchers, (ii) being part of a university and embedded in a student community, (iii) the international character of our institute, (iv) our position in a broad science faculty and among many other scientific institutes at Science Park, and finally (v) the city of Amsterdam. In practice, it is our experience that it is hard to compete with the top US institutions, but that we are competitive in Europe in most fields, despite a smaller size than most top-tier European or international research institutions.

C.3 PhD programme

The general policies set by universities are described in Section .

C.3.1 Context, supervision and quality assurance

Besides the two formal supervisors (either two promotors or a promotor and a co-promotor), IoP policy prescribes that an independent supervisor from a different research group is assigned to each PhD student at the start of his/her PhD. This independent supervisor is a contact person for both the PhD student and the main supervisor(s), should a problem arise between the two. The presence of the second supervisor during the annual interviews ensures that the PhD programme is also reviewed from a wider perspective. Involving an independent supervisor in the PhD programme is intended to prevent stagnation of the project, which can help avoid delays. The independent supervisor was introduced in 2013 and is generally perceived by PhD students as well as staff as a valuable way both for quality assurance and improvement of the well-being of PhD students.

Besides formal annual assessment and progress meetings, the format of the day-to-day supervision is mostly left to the supervisor(s) and the PhD student. In case of problems, the PhD student can request help from the second independent supervisor.

The IoP PhD/postdoc council as well as the IoP support office also play a pivotal role here: they are often the first ones to detect a possible problem, and know the appropriate channels to find help for individual PhD students who need it.

To help new PhD students get to know other members of the institute, the IoP PhD/postdoc council frequently organizes social activities for and a monthly lunch seminar.

C.3.2 Courses for PhD candidates

The partially mandatory "soft skills" programme organized by the Faculty of Science is described on gss.uva.nl/current-phds/skills-development/faculty-level/faculty-program.html. PhD students employed by FOM (now called NWO-I) have a separate set of mandatory/optional courses described at www.nwo-i.nl/en/personnel/information-for-phd-students-and-postdocs/special-courses-for-trainee-researchers/.

In many cases, additional programmes are tailor-made for the PhD students. They are offered the possibility to independently identify relevant course modules, for which the IoP can supply a financial contribution in case the research group cannot cover this. Examples range from Dutch language courses through individual counselling to a programme dedicated to develop our 'Future Leaders'.

C.3.3 Selection and admission procedures

Standard policies are described in Section . The selection of the candidates is done by the supervisor(s) and can include a visit of a few top candidates or a Skype interview. We strongly encourage the involvement of other staff members in the selection procedure. Normally, candidates are invited for a visit, give a seminar and have individual discussions with several group members.

C.3.4 Supervision of PhD candidates and guidance to the labour market

This is described in Section .

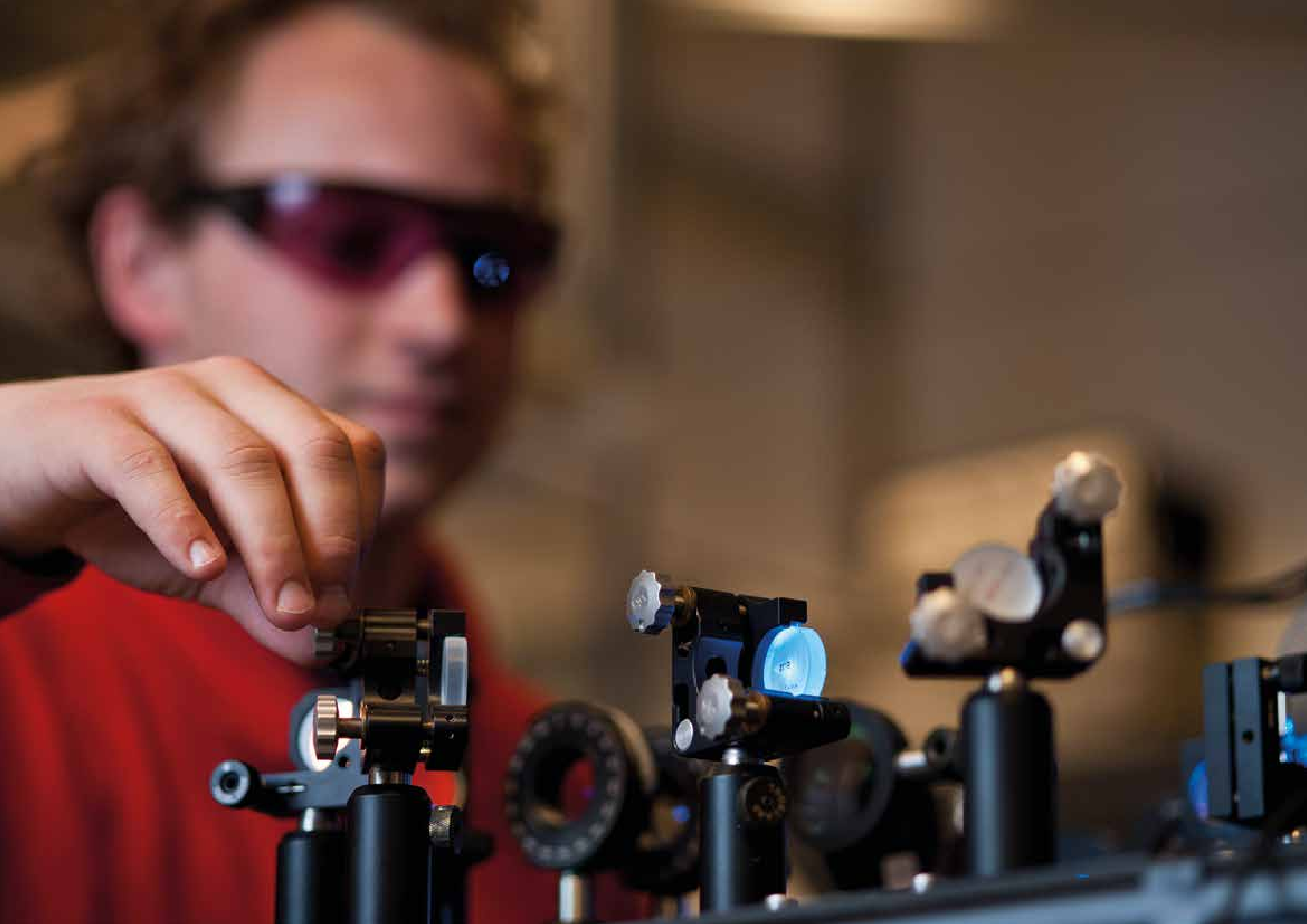
C.3.5 Duration and success rates

We have made a concerted effort over the evaluation period to make sure that every PhD finishes in time as much as possible. Most of our PhD students were financed by FOM (now NWO-I), where a system is put in place for closer monitoring progress of the PhD students, with clearer deadlines and agreements between students and their supervisors. This methodology was adopted for the other (non-FOM) PhD students. The results are positive, both in terms of average PhD duration (FOM /NWO PhD's now take on average 7 months less to graduate than in 2010) and in terms of working pleasure of the PhD students; a new PhD council has been put in place that organizes regular meet-ups for PhD students. The latter also has an important function for signalling potential problems early on. The faculty rule that every PhD student has two supervisors also helps in reducing the PhD duration by making sure that, most of the time, a supervisor is available to help, be it with theoretical or experimental problems. As it has not been very long that all these measures have been taken, we anticipate a further reduction in time to the PhD defence and even less students not finishing their PhD in the near future.

Quantitative information can be found in Appendix F.6.2.

C.3.6 Exit numbers to various sectors

The pie chart in Appendix F.6.2 depicts the sectors of first employment of 67 PhD students after their graduation (excluding those who graduated through external professors by special appointment, such as at AMOLF). The vast majority continues in research, primarily in academia. Unemployment rates after graduation are negligible.



D. UvA+VU Institute for High-Energy Physics (IHEF)

D.1 Introduction

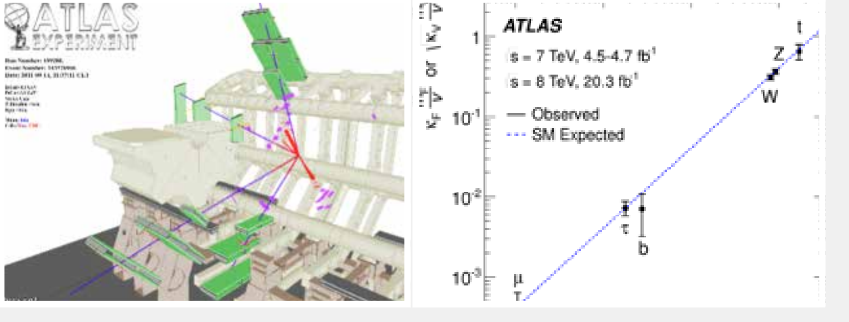
The Institute for High-Energy Physics (IHEF) carries out research in particle and astroparticle physics. For this evlluation, we have chosen to combine the (astro) particle physics sections of both universities, UvA and VU, into one chapter, reflecting their close collaboration. Although the name IHEF originally reflects the division of the UvA's IoP, we have chosen to use the name IHEF also for the combined group. IHEF is an integral part of Nikhef, the Dutch National Institute for Subatomic Physics. The experimental research is carried out in international collaborations at particle accelerators such as those at CERN (Geneva), and within the context of astroparticle physics at locations in France and Italy. UvA physicists within IHEF are active in the ATLAS, Antares/KM3NeT and XENON1T (dark matter) experiments; VU physicists within IHEF contribute to the LHCb and Advanced VIRGO (gravitational waves) experiments. IHEF researchers of both universities are also active in particle physics phenomenology. The Institute of High-Energy Physics of the UvA was an independent research institute within the Faculty of Science until 2011, when it merged with WZI and ITFA into the newly established Institute of Physics (IoP).

The period 2010-2016 was a very exciting one, and included two of the most significant discoveries in physics, both with important IHEF contributions, generating significant media attention. The institute has been able to replace retirees (most of them in 2017) with young talent, and has slightly grown through the

Highlight

ATLAS

A new era in particle physics started in 2012, when the CMS and ATLAS experiments at the LHC announced the discovery of a new particle, compatible with the Higgs boson. IHEF physicists have made major contributions to the design and construction of the ATLAS detector, to the discovery analysis, and to the further studies of the new particle. We have led in particular the analysis of the Higgs decay mode to WW, and contributed to the ZZ decay mode analysis, and measured properties of the new particle such as mass, spin and parity. We have developed the combination framework and fit to determine the couplings of the Higgs boson to fermions and bosons, and are using it to test the Standard Model and search for new phenomena.

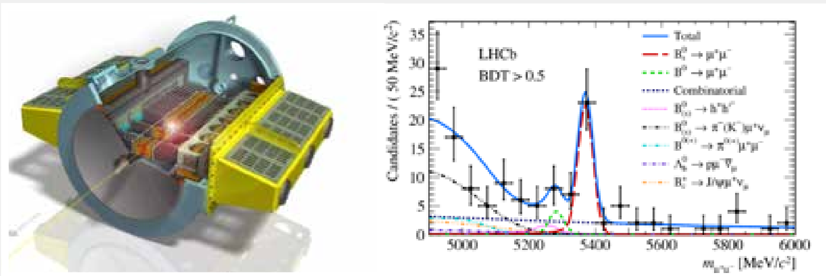


Left: candidate event for Higgs decay into two Z bosons, each decaying into two muons. Right: Measured values of the couplings of the Higgs boson to various particles as a function of the mass of those particles, and comparison with the Standard Model prediction (blue dashed line).

Highlight

LHCb

Rare decays of subatomic particles, suppressed by symmetries of the Standard Model provide excellent opportunities to search for new physics. In 2013, the LHCb collaboration announced first evidence for the observation of the rare decay $B_s^0 \rightarrow \mu^+ \mu^-$. In the Standard Model, this decay is expected to happen for only three out of every billion B_s^0 mesons, but models for new physics allow for significantly different predictions. IHEF physicists led the analysis, and IHEF theorist R. Fleischer gave significant new theoretical insights in the analysis interpretation. Our measurement is in agreement with the Standard Model prediction, and puts constraints on new physics.



Left: artistic impression of a new design for the LHCb vertex locator. Right: Mass distribution of pairs of muons compatible with originating from B meson decay, and the results of the fit.

establishment of the GRAPPA (Gravitation and AstroParticle Physics) centre of excellence at UvA.

Some important developments are listed below:

- 2009: approval of the sector plan Physics and Chemistry, which includes structural funding for astroparticle physics; launch of GRAPPA as RPA at the UvA.
- 2011: GRAPPA receives RPA status plus structural funding from the UvA. A broad search leads to the appointment of Bertone (UvA, 50% IHEF, 50% ITFA) and Decowski (UvA). The UvA-part of IHEF becomes part of IoP; Raven (VU) is promoted to full professor.
- 2012: announcement of the discovery of the Higgs particle by the ATLAS and CMS experiments; De Jong moves from FOM to the UvA;
- 2013: Berge (UvA, 50% IHEF, 50% API) and Bruijn (UvA) are hired. Bentvelsen and Linde receive the Physica Prize. Mulders (VU) receives an ERC Advanced Grant; De Wolf (UvA) retires.
- 2014: Bentvelsen (UvA) becomes Nikhef director; Linde (UvA) becomes chairman of the Astroparticle Physics European Consortium.
- 2015: FOM Valorisation Prize for Van den Brand (VU); Decowski co-recipient of the Breakthrough prize; Snellius Medal for the Dutch ATLAS group; Linde elected as member of the KNAW.
- 2016: The LIGO/VIRGO scientific collaboration announce the first observation of gravitational waves from a binary black hole merger; Van den Brand co-recipient of the Breakthrough prize; Rojo (VU) and Snoek (UvA) are hired.

D.2 Research description

D.2.1 Organization, composition and financing

The two universities UvA and VU are represented in the Nikhef board, together with three other universities, and NWO. Nikhef coordinates the national (astro) particle physics strategy, and interacts with international partners such as CERN. Nikhef functions as home basis for IHEF researchers, and both UvA and VU (astro) particle physicists have their offices there.

The table below gives the composition of the group in the period 2010-2016.

Research Group	**IHEF (UvA-IoP + VU) members** *(Part-time appointments and professors by special appointment in italic)*	Connects to
ATLAS (UvA)	Bentvelsen (now Nikhef director), Berge, Colijn, de Jong, Snoek, Verkerke, Vermeulen, Vreeswijk, van Vulpen, *Koffeman* (Nikhef)[2], *Verkerke* (Nikhef)	Nikhef, ITFA, GRAPPA, Radboud University Nijmegen
LHCb (VU)	Raven, *Merk* (Nikhef)	Nikhef, Groningen University
Gravitational Waves (VU)	Bulten, van den Brand	Nikhef, GRAPPA, Radboud University Nijmegen
Antares/KM3NeT (UvA)	Bruijn, Kooijman, de Wolf, *Koffeman* (Nikhef)[2]	Nikhef, GRAPPA
Dark Matter (UvA)	Colijn, Decowski, Linde	Nikhef, GRAPPA
Detector R&D (UvA)	Colijn, De Jong, *Koffeman* (Nikhef)[2]	Nikhef
Theoretical Particle Physics (VU+UvA)	Bertone, Laenen, Mulders, Rojo, *Beenakker* (RU, Nijmegen), *Fleischer* (Nikhef)	ITFA, GRAPPA, Nikhef Theory Group, Radboud University Nijmegen
Others (UvA)	Bentvelsen (Nikhef director since 2014), *Engelen* (NWO director 2009-2016), Linde (Nikhef director until 2014)	

IHEF is fully integrated in Nikhef. Therefore, it is somewhat arbitrary to identify exclusive contributions of IHEF versus those of Nikhef.

External funding

The FOM programme “Physics at the TeV scale: ATLAS/D0” (total budget 48.1 M€) ran between 1997 and 2014. The FOM programme “LHCb” (total budget 31.7 M€)

[2] Since 2017 a permanent staff member of IoP-IHEF

ran between 1999 and 2014. These grants included funding for PhD students and postdocs, but also investments to construct the Dutch contributions to the ATLAS and LHCb experiments. Since 2015, funding of students, postdocs and membership fees is provided by the combined LHC programme "LHC Physics: the Dutch participation" (2015-2021, main applicant F. Linde, co-applicants P. de Jong, M. Merk, current programme leader S. Bentvelsen). In this programme, 7.5 M€ is reserved for ATLAS, and 5.2 M€ for LHCb. Further funding of detector upgrades is provided by a granted NWO roadmap proposal "Dutch contributions to the detector upgrades of the Large Hadron Collider experiments at CERN" (2013, main applicant F. Linde, co-applicants P. de Jong, M. Merk). This grant includes 5.2 M€ for detector upgrades for ATLAS, 4.0 M€ for LHCb, and 3.7 M€ for LHC computing.

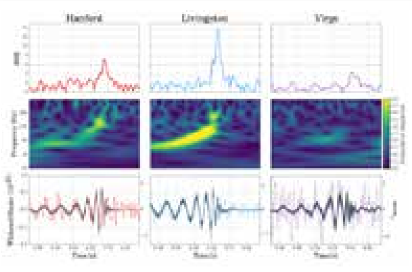
The Gravitational Waves programme received a 1 M€ FOM programme grant ("First detection of gravitational waves with Advanced Virgo" 2015-2020, main applicant J. van den Brand), as well as an NWO-Groot investment grant of 2 M€ ("Advanced Virgo - Probing the dynamics of spacetime", 2012-2016, main applicant J. van den Brand). The Antares/KM3NeT programme was funded by a FOM programme grant "Cosmic ray physics" of 3.8 M€ (2008-2013), combining the physics programmes of Antares/KM3NeT and the Pierre Auger Observatory (no UvA/VU involvement). An NWO investment grant of 8.8 M€ was awarded in 2010, and used to fund Phase 1 of KM3NeT. A new proposal within the NWO "Roadmap for Large Scale Research Infrastructure" scheme of 12.7 M€ has been submitted in 2017 and is under review. The dark matter programme (XENON) was awarded a FOM programme grant of 2.0 M€ ("The missing universe: what is the subatomic constituent of dark matter?", 2013-2018, main applicant M.P. Decowski).

IHEF research in particle physics phenomenology was/is funded by two FOM programmes: "Theoretical particle physics in the era of the LHC" (2.8 M€, 2008-2013, main applicant E. Laenen) and "Higgs as a probe and portal" (2.1 M€, 2015-2019, main applicant E. Laenen).

Highlight

Gravitational Waves

IHEF researchers have made important contributions to the Advanced VIRGO gravitational interferometer near Pisa, Italy, and are members of the LIGO-VIRGO scientific collaboration. In September 2015, the LIGO-VIRGO scientific collaboration announced the first direct detection by LIGO of a gravitational wave, of two merging black holes with surprisingly large masses. IHEF researchers have been members of the detection team, and have used the event to make fundamental tests of general relativity in the strong field regime. In 2017, also VIRGO saw its first events. IHEF researcher Jo van den Brand was elected Spokesperson of VIRGO.



Left: elements of Advanced VIRGO produced at Nikhef. Right: Raw strain data (bottom), signal frequency (middle) and signal-to-noise ratio (top) of a triple coincidence of a binary black hole merger (GW170814) measured with LIGO and VIRGO.

IHEF physicists also received individual funding grants. These include: ERC Advanced Grant for P. Mulders (2.1 M€), funds from an ERC Advanced Grant with P. Kooijman as co-applicant (1.1 M€), ERC Starting Grants for G. Bertone and J. Rojo (1.3 M€), National E-science grants (total of 0.5 M€, Bruijn, Verkerke, Decowski), FOM projectruimte grants (total of 2.4 M€, Mulders, Bentvelsen, Vreeswijk/ Laenen, Fleischer/Merk, de Jong, Rojo), other EU grants (Marie Curie/ITN, total 1.3 M€, Koffeman, Laenen, Van den Brand, Berge, Raven), various FOM grants/prizes (total 1.0 M€, Linde, Van den Brand, Bentvelsen), third parties 1.0 M€ (Van den Brand).

D.2.2 Strategy and targets

IHEF follows two **main directions** of experimental research:

A. Experiments making use of the world's foremost accelerators in terms of centre-of-mass energy and luminosity. Currently these are the ATLAS and LHCb experiments at the Large Hadron Collider, LHC, at CERN, Geneva; before the start of the LHC, IHEF researchers have participated in the ZEUS experiment at HERA, D0 at the Tevatron, and BaBar at SLAC. Activities include detector design and construction, software development, data analysis and development of theoretical predictions.
B. Astroparticle physics: IHEF participates in the Advanced VIRGO gravitational wave interferometer near Pisa, Italy (and thereby also in the LIGO/ VIRGO Consortium), in the Antares/KM3NeT neutrino telescopes in the Mediterranean Sea, and in the XENON direct dark matter detection experiment at the Gran Sasso National Laboratory in Italy.

Experimental physics requires state-of-the-art detectors; R&D for new detectors is an intrinsic part of the IHEF activities.

The **research objectives** are as follows:

A1. To study the mechanism of generation of mass for gauge bosons and elementary fermions. In the Standard Model, mass is generated through the spontaneous breaking of electroweak symmetry by the Brout-Englert-Higgs mechanism. This leads to the prediction of the existence of a Higgs boson with precisely predicted properties, such as its couplings to fermions and bosons.

A2. To search for new particles or interactions beyond the Standard Model, either directly through the detection of new particles, or indirectly through the measurement of quantum effects due to new particles on precision observables, such as CP asymmetries, or rare decays. Observables involving heavy quarks are particularly suited for these studies.

B1. To directly detect gravitational waves from cosmic events involving massive objects, and study their sources. Detectors capable of observing binary black hole and neutron star mergers have an enormous impact in several key scientific areas. Moreover, gravitational wave observations are firmly embedded in the wider field of fundamental physics, astronomy, astrophysics and cosmology.

B2. To detect very-high-energy neutrinos of cosmic origin, identify their sources, and study the properties of neutrinos themselves.

B3. To directly detect interactions of dark matter particles in highly sensitive low-background experiments, and elucidate the nature of dark matter.

There is significant cross-fertilization between the different research objectives and the various experiments. Dark matter, for example, can be studied by detecting direct interactions, but also by studying cosmic sources of neutrinos, and by accelerator experiments at the LHC. Energetic cosmic events may lead to observable gravitational waves, but also to high-energy neutrinos. New phenomena beyond the Standard Model may be studied at the LHC, indirectly through quantum loop effects, but also directly by the study of the production of new particles. Within the Institute of Physics, the GRAPPA centre of excellence is particularly well positioned to exploit this cross-fertilization through multi-messenger approaches.

The aforementioned research objectives are also reflected in strategic choices for future experiments. The LHC will undergo a significant upgrade towards the High-Luminosity LHC in two phases (LS-2 2019-2020, LS-3 2024-2026). Both ATLAS and LHCb are designing and building upgrades to their detectors in order to exploit this new luminosity regime optimally. IHEF researchers are also preparing for the ILD experiment at the proposed International Linear Collider (ILC). VIRGO is preparing a further significant detector upgrade, and studies for a future third-generation interferometer knows as Einstein Telescope are ongoing. In cooperation with Belgium and Germany, the Netherlands is studying the option to prepare a bid to host the Einstein Telescope. A spaced-based interferometer called LISA is also under study. The neutrino programme plans to complete the construction of phase 2 of KM3NeT, consisting of one ORCA building block and two ARCA building blocks, for a total instrumented volume of 1 km^3, and studies a further extension towards a larger detector in phase 3. The study of neutrino interactions, the neutrino mass hierarchy and CP-violation in neutrinos is a target of the ORCA building block of KM3NeT, but IHEF physicists are also exploring participation in LBNF/DUNE, the next generation of accelerator-based long baseline neutrino oscillation experiments. The currently operational XENON1T dark matter detection experiment will be enlarged within a few years to the XENONnT experiment, with IHEF physicists taking the lead in this upgrade. IHEF is also exploring the next generation of dark matter experiments, in particular DARWIN.

D.2.3 Performance indicators

In addition to the usual performance indicator of publications, their citations, and PhD theses, relevant indicators are, given the participation in large international collaborations, invited talks at conferences, lectures at international schools, both personal and on behalf of collaborations, management and leadership positions within these collaborations, and membership of prestigious committees. Additional indicators include the development, construction and commissioning of instruments (hardware) and software required to perform the research. Other indicators are grants, both individual and in collaboration. Societal impact can also be judged by prizes, outreach activities and media presence.

D.2.4 Results achieved

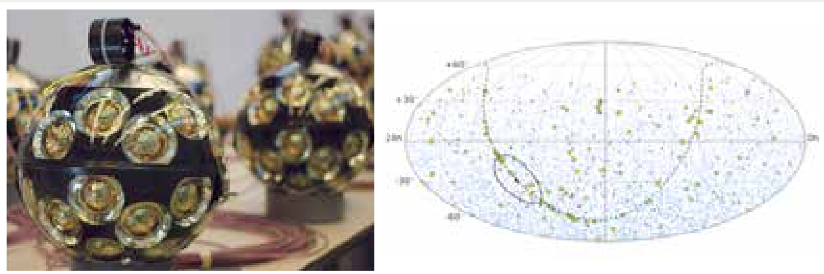
In the period under consideration, IHEF researchers have been part of two of the most significant recent results in physics: the discovery of the Higgs boson at the LHC, and the first direct detection of gravitational waves by the LIGO interferometer. Both are of tremendous importance for our understanding of the universe, and define future directions of research. These breakthroughs are clearly visible in the quantitative results of the IHEF. In the 2011–2016 review period, 1556 refereed citable scientific articles were published in international journals, according to the SPIRES-HEP database, and 45 PhD degrees were awarded.

The production counted per year by the experimental groups increased as data taken at the LHC became available. A detailed breakdown of the scientific publications per experiment of theses and publications is shown in Appendix F.4.3. The differences between the number of SPIRES database entries and that as counted by the experimental groups in the appendix are due to differences in determination of publication dates, missing journals in the SPIRES database and conference contributions not counted in this selection of the SPIRES database.

Highlight

Antares/KM3NeT

The IHEF group has been active in the Antares experiment, which successfully demonstrated the proof of principle for a deep-sea neutrino telescope. We have led the searches for point sources that culminated in the most stringent limits for neutrino sources in the southern sky, using – for the first time – all neutrino flavours. For the much larger neutrino telescope KM3NeT, now under construction, IHEF members have made significant contributions to the design of the detector: the multi-PMT optical module, the electronics, the vertical electro-optical cable, the method to deploy the detection units, and on-line and off-line reconstruction software. First detection lines for KM3NeT have now been deployed.



Left: KM3NeT Digital Optical Module. Right: Neutrinos of all flavours measured by Antares, projected on the sky map (blue and red dots), and locations of catalogue candidate source (other dots).

Note that nowadays most conference papers are refereed and published under the responsibility of the conference organisations.

Typically, experiments in a building phase produce relatively few papers per year, on design studies, hardware, electronics, and beam tests. Running experiments produce a large number of papers per year. Apart from papers in scientific journals, specific contributions are documented in internal notes, which are often also peer reviewed.

Bibliometric analysis of IHEF publications shows a significant rise of the number of publications per year since 2010. This is mostly due to the LHC at CERN becoming operational, resulting in a significant amount of publications of ATLAS and LHCb. In all years, the relative impact, measured by the amount of citations, is above world average; most years have a very good impact, and 2013-2016 can be considered as years of excellent impact. The discovery and further study of the Higgs boson is an important factor here. The number of publications within the top-10% highest cited publications is well above world average by a factor three to five, and every year several publications belong to the top-1% group in terms of citations received. The impact of the discovery of gravitational waves in 2016 is only partially reflected in the bibliometric analysis 2010-2016, since most of it will come in future years. The IHEF publishes almost ninety percent of papers in the first journal quartile with high relative average impact. Although these numbers are for the whole of the collaborations in which IHEF participates, the IHEF always aims to contribute to physics analyses with the highest scientific urgency, and with the most impact. The number of PhD theses submitted per year is nine on average, and fairly constant.

IHEF staff members have given some 280 invited talks and lectures at international conferences over the past seven years. In large collaborations, it is customary that a "Speakers Bureau" handles invitations to high-profile conferences, and distributes the talks to the "most deserving" collaboration members, and IHEF scores well in this respect.

IHEF staff members have been elected or invited into management positions within collaborations. The most prominent election is the one of J. van den Brand to Spokesperson of the VIRGO collaboration. Other notable positions include Technical Coordinator of KM3NeT (E. Koffeman), High-Level-Trigger Project Leader in LHCb (G. Raven), detector working group leaders, editorial board chair and run coordinator in XENON (M.P. Decowski, A.-P. Colijn), and physics working group conveners, publication committee chair and inner detector upgrade integration activity coordinator in ATLAS (W. Verkerke, P. de Jong, M. Vreeswijk).

IHEF members have received a number of prizes in the past years: F. Linde and S. Bentvelsen received the Physica Prize in 2013 (and Van den Brand received it in 2017). In 2015, the ATLAS group received the Snellius Medal of "het Genootschap ter bevordering van Natuur-, Genees- en Heelkunde", and Van den Brand won the FOM Valorisation Prize, and was co-recipient of the Breakthrough Prize in 2016, as was Decowski in 2015. F. Linde was elected to the KNAW (Royal Netherlands Academy of Arts and Sciences) in 2015.

In the period 2010-2016, IHEF staff members have been active as referees and were well represented in editorial boards and scientific committees. Nationally: executive board and deputy chair, advisory board, and executive board of the Subatomic Physics Section of the NNV (Dutch Physical Society), editorial board of the NTvN (NNV monthly magazine), the national Permanent Committee on Large-Scale Research Infrastructure of the KNAW, and the executive board of the learned society "het Genootschap ter bevordering van Natuur-, Genees- en Heelkunde". Internationally: The European Physical Society (executive committee, physics education board, high energy physics board), CERN Council, the European Particle Physics Strategy Group, the European Committee on Future Accelerators (ECFA), the ECFA detector R&D panel (chair), the Astroparticle Physics European Consortium (ApPEC, chair), IUPAP (liaison for the Netherlands), the American Physical Society (fellows), the Particle Data Group, the CERN SPS Committee, the LNGS Scientific Committee, the LAL Scientific Advisory Committee, the Scientific Advisory Committee for Jefferson Lab, the Scientific Advisory Committee of the particle physics group of the university of Louvain, the Fonds Wetenschappelijk Onderzoek Vlaanderen (Expertpanel Physics), the Advisory Board of the Helmholtz Alliance for Astroparticle Physics, the KAGRA programme advisory board, the EGO scientific and technical advisory committee, and the INFN technical scientific committee.

Important output of any experimental (astro)particle physics group consists of advanced particle detectors. For the LHC detectors, most components were constructed between 2002 and 2008, just before this review period. In this review period, specific IHEF contributions include: readout electronics for the ATLAS muon system and the general ATLAS trigger and data acquisition system, design of detector upgrades for ATLAS and LHCb for the next years of LHC running, the multi-PMT digital optical module for KM3NeT and associated electronics, design of the vertical electro-optical cable for KM3NeT, cryostat design and calibration and alignment systems and detector support for XENON1T, and supervision of the design of the thermal compensation system, phase cameras, multistage seismic attenuation systems, cryogenic vacuum links, and elements of the alignment system for Advanced VIRGO. The group is also involved in R&D for future detectors in the form of integrated pixelated gas detectors (GridPix), and medical applications of pixel detectors in the MediPix project.

Software is also important output. IHEF members have developed particle tracking and reconstruction algorithms, and trigger and data acquisition software for ATLAS and LHCb, accurate tracking algorithms and neutrino reconstruction methods for Antares and KM3NeT, data acquisition software and the PAX analysis software for XENON1T, and the data analysis pipeline software TIGER for VIRGO.

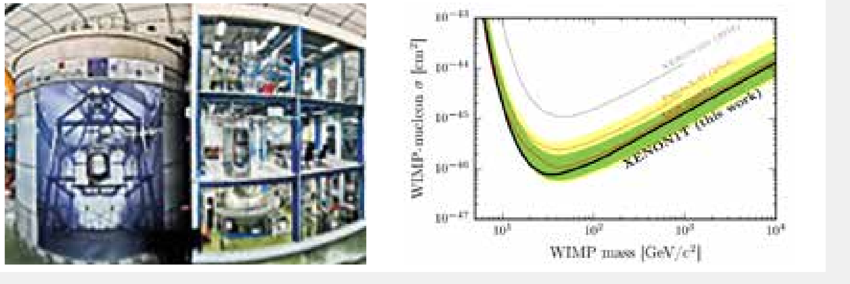
Outside these collaboration-specific contributions, IHEF members have contributed to multi-colour X-ray medical imaging software, and the general data analysis and fitting packages RooFit and RooStats (which play important roles in the Higgs analyses of ATLAS and CMS, as well as rare-decay and CP-violation measurements in LHCb).

Outreach has been a significant activity in the period under consideration. IHEF staff members have given some 250 outreach talks in the past seven years, to the general public, to schools, in science cafes, and to scientific societies. Interest of the general public has been large, triggered by the start-up of the LHC, the discovery of the Higgs boson, the completion of the XENON1T experiment, the first deployments of KM3NeT detection units, and the first detection of gravitational waves. All of these generated significant media exposure on radio and television, in newspapers and in popular scientific magazines. Many journalists have visited CERN or Gran Sasso, accompanied by IHEF members. The children's TV programme "Het Klokhuis" devoted a whole edition to the LHC with prominent presence of IHEF staff. The movie "Higgs – into the heart of imagination" was extended when the discovery of the Higgs particle was announced. Special activities for the general public were organized in association with the celebration of "60 years CERN", and the Technology and Instrumentation in Particle Physics conference in 2014. IHEF members are active on social media.

Highlight

XENON

The chief highlight of the IHEF Dark Matter group over the past years is the completion of the XENON1T dark matter experiment and the start of its scientific exploitation in Fall 2016. XENON1T will be the world's most sensitive direct detection dark matter experiment until the start of the next-generation dark matter experiments in 2020. IHEF members have made large contributions to the detector, to data acquisition and software, and to the analysis of first data, leading to the world's most stringent limits on the spin-independent WIMP-nucleon cross-section.



Left: the Xenon1T detector at the Gran Sasso National Laboratory in Italy. Right: limits on the spin-independent WIMP-nucleon cross section after the first science run of Xenon1T.

D.2.5 Own assessment of quality, relevance and viability

IHEF has a rich and varied research portfolio. The strategic choices that have been made long ago (since lead times in particle physics are long) have paid off extremely well in the period 2010-2016: discovery of the Higgs boson and a wealth of other results from the LHC experiments, first direct detection of gravitational waves, and world-wide highest sensitivity for WIMP dark matter, to name a few. Within the, sometimes large, collaborations carrying out the experiments, IHEF staff have always contributed very significantly to the technical design, the software, the data analysis, and project management. It is our aim to only take part in an experiment if we can make a significant and visible contribution.

IHEF is strongly rooted in Nikhef, which we feel as a major strength. We can make optimally use of the technical and computing infrastructure of Nikhef, and the coordination of Dutch (astro)particle physics by Nikhef provides focus and mass, a strong voice within the large collaborations, and towards institutes like CERN. Within Nikhef, NWO and university-employed staff fully mix. A point of attention is our observation that cross-fertilization between different programmes within Nikhef can still be improved.

The scientific relevance of the obtained results is far-reaching, which is reflected in the strategy of the global particle and astroparticle physics community. We are well aligned with the international strategy of our field, as defined by the European Strategy for Particle Physics (CERN), the ApPEC strategy for astroparticle physics, and the ESFRI list of large-scale research infrastructures. The facilities we use are also listed on the Dutch national roadmap, and we are aligned with Route 5 of the National Research Agenda (NWA).

Our contributions to the upgrades of ATLAS and LHCb are fully funded. The current NWO programme that funds postdocs and PhD students runs until 2021, a follow-up proposal will be submitted in 2020. Phase 1 of KM3NeT (30 lines) is fully funded; a funding request of 12.7 M€ for KM3NeT phase 2 has been submitted to NWO. For upgrades of Advanced VIRGO, an NWO-Groot funding proposal of 2.8 M€ has been submitted. Further funding for students and postdocs in KM3NeT and XENON is to be acquired.

The size of IHEF has slightly grown between 2010 and 2016, this is mainly due to new hires within the GRAPPA centre of excellence. We have been able to replace the retired staff with new, young talent; in recent years on tenure-track positions. Diversity and gender balance remain in need of explicit attention. The two most recent hires were women (E. Koffeman as full professor, H. Snoek as tenure-tracker), but E. de Wolf retired. There is a strong preference for the next hire within GRAPPA to be female. We have no difficulties filling PhD vacancies with excellent candidates; the majority of these come from abroad, whereas the number of PhD students that enrol out of our own Master's programmes needs attention.

IHEF physicists are significant contributors to Technology transfer, education and outreach activities that are part of the mission of Nikhef and in turn also profit from these activities. In the Nikhef context spin-off companies have been established, establishing in 2014 a CERN-Business Incubation Centre. Within Nikhef, IHEF staff currently has collaboration and contract research with Shell, PANalytical, ASML, Tata Steel, and Photonis. Within Nikhef, IHEF provides education at various levels, participating in science tournaments for primary school children known as "Techniek Toernooi". There are opportunities for Master classes, help with school research projects ("profielwerkstukken") and participation for schools in a real scientific experiment through the HISPARC initiative. Last but not least, Bachelor's and Master's students in the joint UvA/VU physics and astronomy programme get acquainted with Nikhef through lectures given by IHEF staff and by performing various projects at Nikhef.

D.2.6 SWOT analysis

Strengths

- Embedding of UvA/VU particle and astroparticle activities within Nikhef.
- Proven initiative and leadership in highly competitive field.
- Strong and balanced physics portfolio in LHC experiments.
- Crucial technical and physics contributions in leading astroparticle physics experiments.
- Good cooperation between experimentalists and theorists.
- Excellent publication and citation record.

Weaknesses

- The particle and astroparticle physics programs at UvA/VU are not exploiting potential synergies. *[Action: stimulate thematic cross-programme activities.]*
- The staff composition shows a significant gender imbalance. *[Action: actively participate in gender programmes; scout female talent.]*
- Large collaborations make it difficult for young people to stand out. *[Action: raise awareness within these collaborations]*

Opportunities

- The general interest of public in fundamental science is strong. *[Action: make use of options offered by the National Research Agenda) to obtain additional funding.]*
- Discovery of the Higgs boson allows further understanding of fundamental physics in the very early universe. *[Action: exploit the LHC luminosity upgrades.]*
- First direct observation of gravitational waves opens a new field in astrophysics. *[Action: increase sensitivity of Advanced Virgo, develop multi-messenger astroparticle physics.]*
- Significant interest in hosting the Einstein Telescope in the Netherlands. *[Action: gather further support to get it built in the Netherlands.]*

Threats

- Significant uncertainties related to the new funding scheme of NWO. *[Action: make funding agencies aware of the needs for coherent funding between university groups and the Nikhef institute]*
- Funding cycles are short with respect to typical experimental time scales. *[Action: make funding agencies aware of long-term strategy needed for big science.]*
- Delays in the start of new large international projects, such as an e^+e^- collider. *[Action: participate strongly in the European particle physics strategy discussion]*
- Insufficient recognition from collaborations for computing efforts. *[Action: keep pressing the need for compensation within collaborations]*

D.2.7 Relevant environmental factors and developments

The research infrastructures used by IHEF staff are listed on the Dutch national roadmap for large-scale research infrastructures. IHEF research also connects well to the National Research Agenda (NWA), which defines spear-points of national research. NWA route 5, “Building blocks of matter and Fundamentals of Space and Time”, is led by S. Bentvelsen.

In 2009, the Sector Plan Physics and Chemistry has generated structural funding for physics, and forced the universities to define research priority areas. The UvA theme “Quantum Universe” fits our research very well. The GRAPPA initiative has furthermore gathered support from the UvA, and has recently been evaluated, resulting in the qualification “very good to excellent”. There is some uncertainty, however, whether the GRAPPA funding provided centrally by the Board of the university is truly structural.

The push for a unilocation of UvA and VU physics has recently collapsed. However, IHEF (UvA-IoP and VU) is already fully integrated within Nikhef, and UvA and VU physicists fully mix with those funded by NWO-I, or other universities. We have decided to maintain the combined monthly group meetings.

A point of concern is the recent reorganisation of NWO. There is significant uncertainty whether the needs for stable long-term funding for big science experiments, as needed to make long-term commitments in collaborations, is fully appreciated by the new NWO. To make an impact, we in particular need coherence between the university investments, and those of the NWO institutes. Furthermore, NWO funding cycles are typically short compared to the needs of experimental particle and astroparticle physics.

D.2.8 International position and benchmark

IHEF research takes place within an international context, and is strongly influenced by the European and world-wide strategies set out for particle- and astroparticle physics. IHEF research aligns very well with the major priorities set out by the European Strategy for Particle Physics as defined by CERN Council, by the ApPEC roadmap for astroparticle physics, and by the ESFRI roadmap for large-scale research infrastructure, which contains the LHC, KM3NeT and Einstein Telescope.

IHEF benefits strongly from its integration within Nikhef. This facilitates a strong and united Dutch voice towards our international partners, and to institutes like CERN. The engineering departments and the workshops at Nikhef enable design and construction of large and technically challenging detectors, which makes us desired partners in international collaborations. This gives IHEF an edge over comparable particle physics groups at universities in other countries that lack such a strong central institute.

A source of concern is the fact that funding cycles at NWO are typically short with respect to the needs of big science, which forces IHEF staff to spend significant time on grant writing. We have observed in this respect that some universities in other countries, like Germany, are better structurally funded, which makes it harder for us to attract, or keep, top scientists.

We list a comparison to some European university groups participating in (astro) particle physics:

- In Belgium, the group at VUB is comparable in size to us, and with a similar LHC and astroparticle physics portfolio. The groups in Antwerp and Gent are smaller;
- In Sweden, the groups in Stockholm, Uppsala and Lund are all slightly smaller. Stockholm has a well-known astroparticle and dark matter group, Lund is known for its excellence in phenomenology;
- In Denmark, the group at the Niels Bohr Institute in Copenhagen is slightly smaller, with a focus on ATLAS, heavy ion physics in ALICE, IceCube and theory;
- In Spain, IFIC Valencia is very comparable to us, in size, in portfolio, and in their ability to design and construct detectors. The group at IFAE Barcelona is larger, with a wider portfolio in astroparticle physics;
- In France, groups at CPPM (Marseille) and LAL (Annecy) are larger than we are, with more activities in astroparticle physics experiments;
- In the United Kingdom, Oxford and Cambridge are significantly larger than we are. However, we are comparable in size and portfolio to Imperial College London, Manchester, Liverpool and Edinburgh;
- In Germany, the group in Freiburg is comparable to us, Heidelberg is somewhat larger, Bonn and LMU somewhat smaller. Two universities that have close ties to a national particle physics laboratory are the Humboldt University in Berlin (DESY Zeuthen) and the University of Hamburg (DESY Hamburg). The group in Hamburg is smaller and CMS is its main activity, the group in Berlin is slightly larger than us, with a slightly larger portfolio, mostly in astroparticle physics.

D.3 PhD programme

The general policies set by universities are described in Section .

D.3.1 Context, supervision and quality assurance

PhD students in High-Energy Physics are enrolled either in the Research School for Subatomic Physics (OSAF) or the Dutch Research School of Theoretical Physics (DRSTP). Through the OSAF and DRSTP institutions, the tutoring and supervision are organized and aligned. Specific, educational programmes are developed by the two Research Schools. The description here pertains to OSAF; DRSTP is described in the ITFA section.

D.3.2 Courses for PhD candidates

Following general requirements and regulations towards education, a dedicated programme has been set up at Nikhef, in which IHEF students have to attend at least six topical lectures during their PhD trajectory. These are intensive three-day courses, taught by scientists from OSAF and international experts on topics relevant to subatomic physics. In addition, during their first two years, PhD candidates are required to attend a two-week (summer) school, which is jointly organized between Germany, Belgium and the Netherlands[3]. Students provide feedback after each topical lecture and school. Their feedback is discussed in the Education Committee and used to improve the quality of the lectures.

During the third year it is common that an international school is attended. In principle the candidate can propose any school, provided it is a good match with the research programme and has the appropriate level. A majority chooses to attend the CERN European school of physics. Others have opted in recent years for schools at the Stanford Linear Accelerator Center in California, and Fermilab near Chicago. Finally, PhD candidates are expected to regularly attend local seminars and colloquia.

As research in particle and astroparticle physics is typically performed within large international collaborations, there are experiment-specific training requirements for the operation of large-scale detectors, as well as training opportunities for the techniques employed by these collaborations.
With the vast majority of IHEF/Nikhef PhD students being employed by NWO-I (previously FOM), they typically enrol in the soft-skills training package organized by NWO-I.

D.3.3 Selection and admission procedures

PhD candidates are selected for externally funded, peer-reviewed projects (NWO, EU). Most PhD positions are externally advertised. The selection committee consists of the direct supervisor(s), (co)promotor(s), the programme leader of the relevant research programme, and possibly additional members of the Nikhef collaboration.

D.3.4 Supervision of PhD candidates and guidance to the labour market

Progress is monitored by means of progress interviews. The student, the supervisor(s) and an independent member of Nikhef's Education Committee (together called C3 committee) meet and discuss the progress of the thesis work, training of the student, assess future plans and evaluate the quality of the supervision. Progress interviews contain both a look at past performance and a discussion of

[3] bnd-graduateschool.org/

future steps. Interviews are held after 6, 12, 24, and 36 months. The independent member of the Education Committee reports at the meeting of the full education committee on the progress of the PhD student. When the 6-months interview leads to serious doubts about the student's ability to complete the PhD programme, progress can be monitored more closely and a go/no-go decision could be taken within the first 12 months. The independent member can also advise to replace the supervisor in case of problems with the supervision. Students are also briefed on the end terms of the thesis, rules on plagiarism, and receive advice towards a timely completion of the thesis.

PhD candidates are encouraged to participate in courses preparing them for the labour market, both within and outside academia. The highly valued 'soft skills' courses offered to PhD students employed by NWO-I, are also available to university-employed PhDs. These courses not only aim at scientific writing and presenting scientific work, but also focus on 'giving shape to your career', in which PhD students actively explore their future possibilities on the labour market. Whenever desired, additional coaching and support is offered.

Since PhD students in particle- and astroparticle physics partake in large international collaborations and can be stationed for extended periods at international laboratories such as CERN, they have the opportunity to build up an international network, with the help of their supervisors.

D.3.5 Duration and success rates

As can be seen in Appendix F.6.3, the median length of PhD candidacies (from start of contract to actual defence) in the period 2010-2016 is about 54 months. This is still 6 months longer than the nominal length of contract, and this undesired fact has our attention. Typically, 3-4 months are needed for formalities between the completion of the thesis and the actual defence. Within large collaborations, PhD students are more dependent on external factors than students with table-top experiments in their own laboratory; external factors include availability of centrally processed data sets or external inputs, synchronization with other analyses in single papers, or general data un-blinding or publication policies. The large collaborations are becoming more aware of the constraints on PhD lengths imposed by the contributing universities.

D.3.6 Exit numbers to various sectors

Particle- and astroparticle PhD graduates easily succeed in finding jobs following their defence. Although we lack exact figures on the employment of all alumni, the pie chart in Appendix F.6.3 provides information on the various sectors in which recently graduated PhD students are currently employed. The figure is based on data from OSAF about 35 PhD students of Nikhef (i.e., not exclusively IHEF) who graduated in 2014 and 2015.


H = 1/2m (p - qA)^2 + V(r)
E
J = L+S

E. UvA Institute for Theoretical Physics Amsterdam (ITFA)

E.1 Introduction

The Institute for Theoretical Physics Amsterdam (ITFA) has a long and distinguished history. It was an independent institute from the late 1940s until 2010, when it merged with two more experimentally oriented physics institutes to form the Institute of Physics (IoP). The ITFA stimulates collaboration with experimental groups, exemplified by its active participation in the research priorities GRAPPA and Soft Matter and the QuSoft centre. But it also has a unique culture of fostering theoretical work that transcends the boundaries between different specializations, producing researchers and collaborations that bridge the gaps between different fields of theoretical physics.

The years 2010-2016 have been quite exciting and successful for the ITFA. The institute was significantly rejuvenated by new hires and at the same time grew considerably in size. The theoretical physics track in the MSc programme more than doubled in size during this period, and we now see as many as 70 students sign up for courses such as general relativity and quantum field theory. A summary of the most important developments:

- 2009: approval of the Sector Plan Physics and Chemistry, which included structural funding for astroparticle physics; launch of GRAPPA
- 2010: ERC Advanced Grant Verlinde and NWO Vici grant Caux
- 2011: GRAPPA receives RPA status plus structural funding from the University. A broad search leads to the appointment of Bertone, Ando and Freivogel; NWO Spinoza prize Verlinde; Bais retires. ITFA becomes part of IoP.
- 2012: Taylor and Skenderis leave for Southampton; Delta ITP gravitation grant awarded; Turner is appointed. Schoutens becomes acting Dean of the Faculty of Science.
- 2013: van der Schaar (Delta ITP coordinator), Hofman, Castro join. Turner leaves. Weniger joins, van Dongen is hired; Kox, Pruisken retire.
- 2014: Cheng joins with a MacGillavry Fellowship; Gritsev (Delta ITP), Corboz, Waalewijn (Delta ITP) and Lerner (AAA fellow) are hired; van Wezel joins. Schoutens returns to ITFA.
- 2015: Baumann (AAA fellow) joins. QM-QI receives RPA status.
- 2016: Vonk is hired to strengthen our research-based outreach efforts.

Highlight

Umbral moonshine

***Reference**: M. C. Cheng, J.F. Duncan, J.A. Harvey. Umbral Moonshine and Niemeier Lattices. Math Sci (2014) 1: 3*

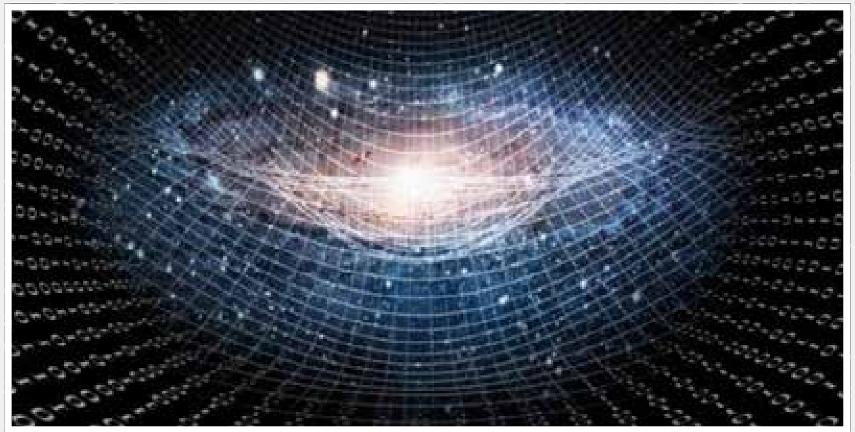
The word moonshine refers to unexpected relationships between two branches of mathematics: so-called modular forms, and representations of finite groups. These relationships turn out to have roots in string theory leading to a rich interplay between physics and mathematics. ITFA researchers discovered many new examples of moonshine, including a class called “umbral moonshine”, and found many new features, suggesting that moonshine is a much more general phenomenon than previously thought, whose precise nature remains a fascinating mystery.

Highlight

Emergent gravity; black hole entanglement and quantum error correction

***References**: (1) Erik P. Verlinde. Emergent Gravity and the Dark Universe. SciPost Phys. 2 (2017) no.3, 016; (2) Erik Verlinde, Herman Verlinde. Black Hole Entanglement and Quantum Error Correction. JHEP 1310 (2013) 107.*

In recent years, a lot of progress has been made in understanding the emergence of spacetime using concepts of quantum information theory, in particular quantum entanglement. ITFA researchers were the first to explain the important role of quantum error correction in the emergence of spacetime. ITFA researchers also have proposed that in expanding universes like our own this leads to deviations of general relativity at long distances, in many cases leading to observed phenomena in galaxies and clusters currently attributed to dark matter.



Curved spacetime around a galaxy, with information entropy at larger distances causing additional elastic component to gravity.

Creation of University-wide Vossius Center for history of science (co-directed by van Dongen).

- 2017: QSC (Quantum Software Consortium - QuSoft plus groups from Leiden and QuTech Delft) is awarded an NWO Gravitation Grant; Ozols, Walter join as part of QuSoft; ERC Advanced Grant Caux.

As this list illustrates, there has been a lot of dynamics in the ITFA during the past couple of years. The growth of the institute was mostly made possible by external developments and successful grant applications: many individual grants, but more importantly the Sector Plan, the research priority area policy of the UvA, the introduction of AAA fellows as part of the UvA-VU collaboration plans, the MacGillavry Fellowship programme of the Faculty, and last but not least, the successful applications of Delta ITP and QSC in the NWO Gravitation Grant scheme.

E.2 Research description

Researchers at ITFA perform research around various research themes. The strength of the ITFA is that these themes are tightly linked together and strongly overlap. In the description below, this redundancy is seen as the repeated occurrence of the names of staff members involved in multiple programmes. It should be emphasized that these themes do not represent organizational units, and in particular do not have a group leader. They have been chosen to provide insight in the members and current research activities of the ITFA. Most themes, but not all, have regular group meetings and seminars by external speakers.

E.2.1 Organization, composition and financing

An overview of the main research themes plus involved staff members is provided in the table below.

Theme	ITFA members	Connects to
Soft Condensed Matter	Lerner, Nienhuis	WZI Soft Matter group/ Soft Matter RPA
Quantum Condensed Matter Theory	Schoutens, Caux, Corboz, Gritsev, van Wezel, Nieuwenhuizen	WZI Quantum Matter group/QMQI RPA
Astroparticle Physics/ GRAPPA	Bertone, Ando, Weniger, Freivogel, Nieuwenhuizen	Other members of Grappa: API, IHEF
String Theory	Verlinde, de Boer, Castro, Hofman, Cheng, Baumann, van der Schaar, Freivogel, Vonk	Other national string theory groups through joint programs
Cosmology	Baumann, Freivogel, van der Schaar	Nikhef Theory Group, national cosmology program
Mathematical Physics	De Boer, Caux, Cheng, Gritsev, Nienhuis, Verlinde, Vonk	KdVI
Theoretical Particle Physics	Laenen, Waalewijn	IHEF and Nikhef Theory Group
History of Physics	Van Dongen	Faculty of Humanities, ILLC
QuSoft center	Schoutens, van Wezel, Ozols, Walter	Other members of QuSoft consortium, KdVI, ILLC

In contrast, the composition in 2010 was:

Theme	ITFA members
String Theory and Quantum Gravity	Dijkgraaf, Verlinde, de Boer, Skenderis, Taylor
(Astro)Particle Physics and Cosmology	Bais, Laenen, Nieuwenhuizen
Low-D Quantum Condensed Matter and Quantum Information	Caux, Schoutens, Pruisken
Complex/Collective Phenomena	Nienhuis, Nieuwenhuizen
History of Physics	Kox

Clearly, both in size and in research scope, the ITFA has grown considerably during the review period. This applies not only to the permanent staff but also to postdocs and PhD students as can been seen in the table in Appendix F.6.3. It illustrates that the new staff members have been very successful in obtaining grants, as grants are the primary source of funding for both PhDs and postdocs.

Several of the ITFA staff members have joint appointments with other institutes, which is one of the mechanisms by which we seek new collaborations and ideas: Bertone has a joint appointment with the IHEF (50%/50%), Cheng a joint appointment with KdVI (50%/50%), Laenen a joint appointment with the IHEF and the University of Utrecht (40% ITFA/40% IHEF/20% UU), and Ozols and Walter have a joint appointment with KdVI and ILLC (33%/33%/33%).

The governance of the ITFA is aimed at having as little hierarchy as possible. The ITFA has a single head (currently de Boer) who is also part of the management team of the IoP. Annual reviews of all staff members are conducted by the head of the ITFA. While formally the director of the IoP is responsible for the entire institute, the three divisions have a substantial amount of autonomy and within ITFA we try to take decisions as much as possible by consensus. Staff meetings, which takes place every other week or so, serve to exchange information, discuss teaching, discuss ideas to improve the institute and draw attention to important strategic developments and upcoming grant deadlines[4]. During biannual retreats, staff members discuss strengths, weaknesses, threats and opportunities and the ITFA strategy. Occasionally, on an ad hoc basis, groups are formed to discuss things like the computational infrastructure or plans to promote the theoretical physics MSc programme. Whenever circumstances so dictate, Human resources matters are sometimes discussed with some of the more senior staff members of the ITFA. Matters such as tenure and promotions are also discussed by the IoP directorate where, again, decisions are generally made by consensus.

Formally, the ITFA does not have its own independent direct budget, but within the IoP we do keep track of the different budgets of the three divisions. Besides base funding received directly from the Faculty of Science, there is a flexible funding component determined by the amount of teaching of ITFA employees and the number of PhD theses.

[4] The theoretical physics colleagues from the VU (Mulders, Rojo, Stephens) are actively participate in the staff meetings and strategic retreats.

Besides this, there are various individual and collaborative grants, RPA funding, and long-term (but not permanent) funding through NWO Gravitation Grants. There is presently no funding from industry nor is the ITFA involved in contract research.

E.2.2 Strategy and targets

The main mission of the ITFA is perform world-class research in theoretical physics and to teach and train students, PhD students and postdocs accordingly. Theoretical physics differs from many other disciplines in that it does not require a large infrastructure and a corresponding long-term planning. Rather than working with, say, a top-down five-year research plan, for instance, we view the institute primarily as a facilitator of top quality research. We do this, among others, by providing broad professional support for staff members and research groups, by encouraging collaborative projects inside and outside the institute, by continuous attention to PhD recruiting and monitoring, by continuously scouting for new (funding) opportunities[5] and new talent, and by maintaining a strong outreach programme. To be competitive, groups working in particular research themes should have sufficient critical mass, which is another aspect we closely monitor. When vacancies occur, hiring decisions should ideally be based on strategic discussions in the institute. In practice, funding opportunities and associated positions often arise unexpectedly, so that our hiring has been somewhat opportunistic. Nevertheless, the institute in its present form is a constellation of excellent research and people, and we are therefore confident that we are well-equipped to fulfil our mission well for the foreseeable future. Theoretical physics

[5] For example, possibilities to obtain funding for GRAPPA and Delta ITP were anticipated years before they materialized, and by organizing various scientific activities and strategic discussions prior to the appearance of an actual call gave us an important advantage.

is very much a field driven by grand challenges. They inspire the research themes at the ITFA, and thereby to a considerable extent define what the ITFA is all about[6].

Thus, the unknown nature of dark matter and dark energy is very much in our focus, from the foundational aspects to the phenomenology that would help elucidate this issue. The investigation of the microscopic quantum nature of spacetime and gravity is a traditional strong point of the ITFA research, in particular the implications back and forth for black holes, cosmology, gravitational waves and possible observable consequences. We have a strong effort in cosmology, addressing the issue how the universe began, what the origin of structure in the universe could be, what the initial conditions of cosmological inflation were.

Another aspect of the investigation into microscopic quantum aspects of spacetime is the question if and how we can formulate quantum field theory from first principles away from weak coupling, possibly through the AdS/CFT correspondence. Curiosity about the fundamental aspects of matter and force compels us to increase the accuracy of theoretical predictions, and to propose and investigate new observables to search for physics beyond the Standard Model at the Large Hadron Collider.

An important part of our research is driven by the aim to understand the quantum structure of materials, chemistry, and spacetime itself through quantum simulation or quantum computation. Essential questions about larger aggregates of matter drive us, too, such as what the possible phases of matter are, and what type of new phenomena can emerge in quantum many-body systems in and

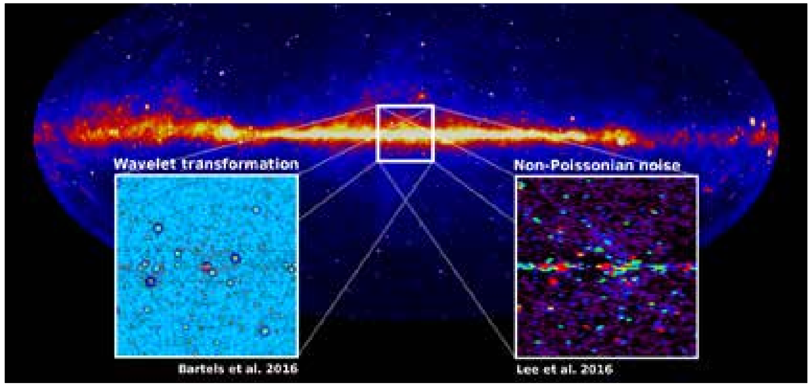
[6] Our grand challenges have significant overlap with questions 124-130 of the national research agenda (wetenschapsagenda.nl/publicatie/nationale-wetenschapsagenda-nederlands/).

Highlight

Strong support for the millisecond pulsar origin of the Galactic centre GeV excess

Reference*: Strong support for the millisecond pulsar origin of the Galactic center GeV excess. Richard Bartels, Suraj Krishnamurthy, Christoph Weniger, Phys.Rev.Lett. 116 (2016) no. 5, 051102*

The observation of unexpectedly strong emission of photons with GeV energies from the Galactic center bulge since 2009 by Fermi LAT has caused a significant amount of excitement as the signal seemed compatible with self-annihilating dark matter. Using a newly developed wavelet fluctuation analysis, researchers at ITFA have shown that the most likely origin of this GeV signal is not dark matter but the combined emission of hitherto unobserved millisecond pulsars (MSPs) and were able to detect the brightest MSPs around the detection threshold of Fermi LAT. Dedicated searches with new radio telescopes to confirm this result are underway.



out of equilibrium. And can we understand, or even predict, the properties of novel materials with new interesting functionalities? Finally, zooming out again, can we connect microscopic physics (interactions, disorder, chaos) to macroscopic phenomena (complex emergent phenomena, critical behavior, mechanical response)?

Important strategic decisions of the past evaluation period include:

- Build a new astroparticle physics group: this has by all means been a great success with GRAPPA now being well-known worldwide.
- Maintain a strong effort in string theory despite the departure of Dijkgraaf, Skenderis and Taylor: this was clearly achieved thanks to the hiring of Freivogel, Castro, Hofman, Cheng, Baumann, van der Schaar and Vonk.
- Improve the diversity of the ITFA: an important step was made with the hiring of Castro and Cheng.
- Maintain interdisciplinary high-end research in history of physics: this was achieved with the hiring of van Dongen after the retirement of Kox.
- Strengthen the quantum condensed matter theory group: this was realized through the hiring of Corboz, Gritsev and van Wezel.
- Strengthen activities in soft matter: this was partly achieved with the hiring of Lerner.

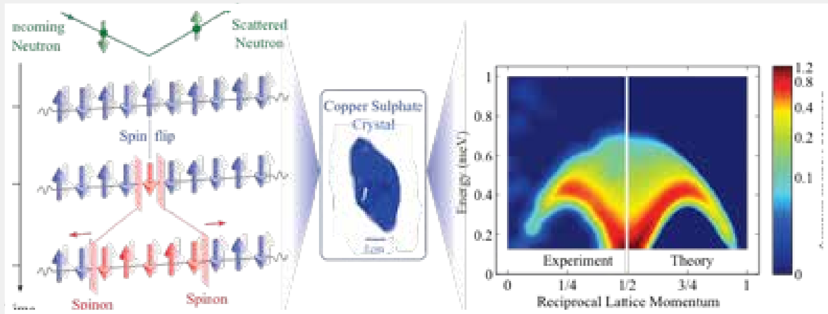
E.2.3 Performance indicators

A standard performance indicator is publications and citations. It is interesting to note in this context that within certain fields whether or not papers are published is losing relevance. Instead, it is sufficient to put the papers on the ArXiv, the idea being that the community will automatically identify important work and ignore wrong and irrelevant work anyway. From this point of view, the number of invitations to speak at workshops and conferences, to lecture at schools and

Highlight

Fractional spinon excitations in the quantum Heisenberg antiferromagnetic chain

Recently, a team of experimentalists based in Lausanne has obtained detailed and accurate measurements of Inelastic Neutron Scattering cross sections in quantum spin chains realized in crystals, which were then compared to detailed theoretical predictions from methods of integrability obtained by ITFA researchers. The result is a compelling quantitative comparison between the measured signal and the microscopics-based theory, opening the door to a much deeper understanding of many-body quantum dynamics in such strongly interacting systems.



Fractional spinon excitations in the quantum Heisenberg antiferromagnetic chain, M. Mourigal, M. Enderle, A. Klöpperpieper, J.-S. Caux, A. Stunault, H. M. Rønnow, Nature Physics 9, 435-441 (2013).

give colloquia, are perhaps equally important indicators of quality. Nevertheless, publishing papers in journals remains important for certain job applications, grant applications, and research reviews. It is noteworthy that one of the members of the ITFA, Jean-Sébastien Caux, has created an innovative scientific publishing platform called SciPost, which is 100% free and 100% open access.

Other important performance indicators are the number of PhD theses, individual and collaborative grants obtained, involvement in (inter)national collaborations, prizes and distinctions, editorships, prestigious memberships, etc.

The ability to attract talent as evidenced by the number of applications for PhD, postdoc and staff openings is also a good indicator of the international standing of the institute.

Regarding societal relevance, given our position, indicators are (i) the number of activities for high-school students and their attendance, (ii) the number of activities for high-school teachers and their attendance, (iii) the number of activities (popular books, lectures, (social) media presence, events, website columns) for the general public, (iv) joint projects with external stakeholders. Ideally, one would like to measure the impact rather than the number of activities, but this is notoriously hard. Nevertheless, we are presently exploring various ways to measure impact but this is still in its infancy.

E.2.4 Results achieved

The bibliometric analysis summarized in Appendix F.5.4 reflects the growth of the institute both in quantity as well as quality. We proudly observe that the number of publications is rising steadily, with the last few years featuring excellent research impact numbers, the fraction of top-10% publications rising to 54% and the fraction of top-1% publications rising to 13%.

Output indicators are contained in Appendix F.4.4. The number of invited talks at conferences and workshops grew from 29 in 2010 to 88 in 2016, the number of invited seminars/colloquia grew from 26 to 63. The numbers also clearly demonstrate that our staff are increasingly often asked to lecture at schools, and that our involvement in the organization of schools, workshops and conferences is steadily increasing as well. Editorships have grown from 3 in 2010 to 14 in 2016. As above, these numbers reflect an increase in both quantity and quality of the institute.

The number of PhD theses awarded during the review period can also be found in Appendix F.6.4. The strong growth of the institute and the success in obtaining funding is not yet visible in these numbers, as e.g. PhDs awarded in 2016 were in general funded by grants obtained in 2011 or earlier. It is more significant to note that at the end of 2016 no less than 41 PhD students were employed at ITFA. Of the 34 PhD theses awarded from 2010-2016, three were awarded with the distinction *cum laude*: Balt van Rees (2010) Milosz Panfil (2013) and Daniel Mayerson (2015).

During the review period, ITFA staff were extremely successful in obtaining external grants, which include 1x NWO Vici, 4x NWO Vidi, 2x AAA Fellowships, 1x ERC Advanced, 1x ERC Consolidator, 6x ERC Starting, 8x FOM Projectruimte, 1x NWO Humanities grant; we participated in 8 FOM Programmes, GRAPPA received RPA status and an NWO graduate programme grant, and we obtained a 10-year Delta ITP Gravitation Grant. QM&QI received RPA status and addition funding through the University Board and the Faculty of Science. In 2017 we furthermore obtained one more ERC Advanced Grant and the QSC Gravitation Grant.

From 2010 to 2016, we participated in 2 ITN and 4 COST networks, one ESF programme and one Marie Curie IRSES programme; we are also collaborating with three separate Simons Collaborations.
ITFA members received several honours and distinctions. We mention the Emmy

Noether Fellowship at the Perimeter Institute of Alejandra Castro, an associate fellowship at Homerton College in the University of Cambridge for Jasper van Wezel, a distinguished professorship of Theo Nieuwenhuizen at the IIP Natal, the membership of the Young Academy of Europe of Bertone, the 'Ciel et Espace' prize for best astronomy book for Bertone, memberships of the Royal Holland Society of Sciences and Humanities for Kareljan Schoutens and Erik Verlinde, and last but not least the NWO Spinoza Prize awarded to Erik Verlinde in 2011.

All PhD and postdoc vacancies are advertised on the IoP website but recruitment is not done in a universal way. Sometimes researchers recruit jointly with the entire group or in European collaborations, sometimes they recruit individually. For example, in the string group we annually receive more than 120 applications for PhD positions and around 450 for postdoctoral positions (the latter in a joint call with other European Institutes). In GRAPPA, PhD and postdoc openings also tend to receive more than 100 applications, all indications of the international reputation of the corresponding groups.

As can be seen in Appendix F.4.4, the number of activities with/for various external stakeholders has increased during the past years with the appointment of Marcel Vonk as part-time outreach officer. For high-school students we supervise several research projects ("profielwerkstuk") each year, we offer an annual master class and participate in the annual event "Viva Fysica". An important outreach opportunity for theoretical physics was the introduction of a new physics curriculum for the Dutch high school exams in 2016, in which quantum physics (required) and special relativity (optional) appeared as new subjects. For each of these subjects, a series of three teaching modules was developed. Moreover, to support high-school teachers who are not always very familiar with these topics, we have been organizing local teacher's courses in relativity since 2013 and have organized the nation-wide quantum physics course in the Natk4all teacher's education programme since 2015. Through Delta ITP, and we support the junior physics Olympiad. Outreach activities are numerous and include TV appearances in "Universiteit van Nederland", children's lectures in NEMO and Paradiso, the so-called FNWI college tour, maintenance and content creation for the popular science website quantumuniverse.nl, and several dozens of popular scientific lectures by ITFA members each year. A few other highlights can be found in Appendix F.8.4.

We presently have no ongoing collaborations with industry but QuSoft is presently exploring such collaborations and will keep an eye out for the opportunities that the new APRIL initiative brings. We would also like to point out our relation with industry through the industry advisory board of DeltaITP and the special Delta ITP programme "Theory in Practice" for Master's students where they get to work on concrete cases in various organizations/companies. Through the EU training network HiggsTools (2014-2017), we had frequent contact with Shell Research regarding secondments of ESRs at Shell Rijswijk.

E.2.5 Own assessment of quality, relevance and viability

Quality

As evidenced by the performance indicators and results obtained, the research done at the ITFA is in general of very high quality, and the last years have seen an upward trend in both quality and quantity of the research output. We have hired many new and talented scientists with different backgrounds and expertises, for all vacancies we had a large number of qualified applicants. The fact that we obtained an NWO Gravitation Grant for Delta ITP in 2012 is in our opinion very significant in this respect: this was a large grant for a consortium consisting of three theoretical physics institutes with a research programme which captured most of the research at the ITFA. We were one of the five Gravitation Grants awarded in that year among applications across all disciplines. Our participation in the QuSoft consortium which obtained another Gravitation Grant in

2017 is a further confirmation of our quality. With a large number of seminars, journal clubs, colloquia and informal discussions there are many opportunities to interact within and outside one's own discipline, creating a stimulating research environment.

Relevance

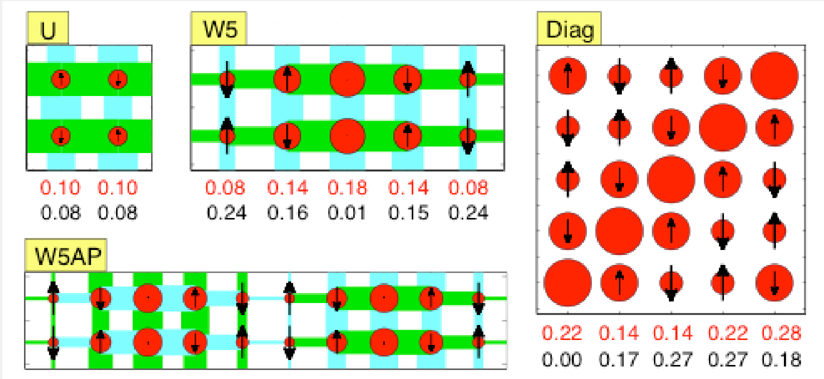
The research done at the ITFA is typically fundamental and curiosity-driven. While history has shown that this type of research often eventually leads to practical applications, the associated timescales tend to be rather long, with theory contributing just one of the pieces of a bigger puzzle. Therefore, the short-term return on investment of our research (which some politicians so desire) tends to be rather limited. There are of course examples of work where the connection to applications is more explicit: work on traffic and traffic jams, research on high-Tc superconductivity and on novel materials together with experimental groups, and the work of QuSoft which attracts significant interest from industry and feeds back into commercial activities in e.g. Delft. A more indirect example is the through the appointment of Eric Laenen as the Netherlands scientific delegate to the CERN council, where he is quite active to ensure more participation of students from Dutch vocational education programmes (MBO/HBO) at CERN; and helps to increase the value of contracts awarded to Dutch industry.

Highlight

Competing states in the t-J model: uniform d-wave state versus stripe state

***Reference**: Competing states in the t-J model: uniform d-wave state versus stripe state, P. Corboz, T. M. Rice, and M. Troyer, Phys. Rev. Lett. 113, 046402 (2014).*

The nature of high-temperature superconductivity in the cuprates remains elusive. A well-known model, the Hubbard model, may explain superconductivity but is notoriously difficult to study accurately. Recently, ITFA researchers have achieved a breakthrough in studying the t-J model, which is an effective description of the Hubbard model in the strongly interacting limit. Using State-of-the-art tensor network simulations an extremely close competition between a uniform d-wave superconducting state and different stripe states was found, with a substantially higher accuracy than in previous works. Nature appears to be close to the transition point between the two states, as both states are indeed observed in different cuprate materials.



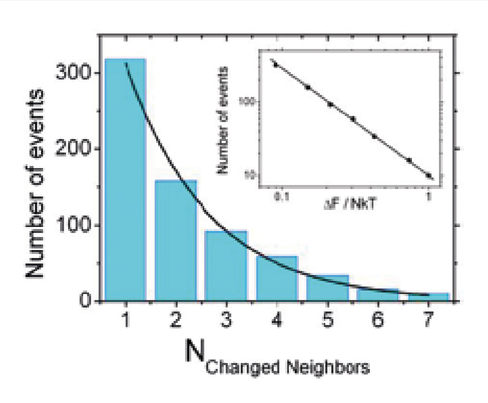
Competing states in the t-J model. The red dots, arrows, and coloured bonds scale with the local hole density, local magnetic moment, and pairing amplitude, respectively.

Highlight

Direct Measurement of the Free Energy of Aging Hard Sphere Colloidal Glasses

***Reference**: Direct Measurement of the Free Energy of Aging Hard Sphere Colloidal Glasses, R. Zargar, B. Nienhuis,P. Schall, D. Bonn, Phys. Rev. Lett. 110, 258301 (2013).*

In spite of extensive research over many decades, the nature of the glass transition is one of the important unsolved questions in condensed matter physics. The difference between glasses and liquids is believed to be caused by very large free energy barriers for particle rearrangements. However, so far, it has not been possible to confirm this experimentally. ITFA researchers provided the first quantitative determination of the free energy for an aging hard-sphere colloidal glass. They found that the probability of particle rearrangements have a probability that depends as a power law on the associated change in free energy, analogous to the Gutenberg-Richter law for earth quakes (see figure).



Arguably our most important contribution to society is through education and outreach. The grand challenges that guide and inspire our work are also precisely the big questions which capture the imagination the general audience and of primary and high-school students and is often the reason why they choose to study physics in the first place. In our complex high-tech world there is an ever-increasing demand for people with an MSc of PhD in the natural sciences with strong analytical and problem-solving skills. We contribute significantly to this demand by attracting (inter)national talent at the BSc, MSc, PhD and even postdoc level and providing them with the best possible education and research training, and we notice that a substantial fraction of our PhD students (see Section) does indeed bring these skills to jobs outside of academia.

Viability

The viability of an institute such as the ITFA is intricately linked to several factors: student numbers, rejuvenation and innovation potential, finances, and strategic position in the local and (inter)national landscape. These shape the important strategic goals and targets for the present and future.

Student numbers: During the evaluation period the number of Bachelor's and Master's students did fluctuate quite a bit but on average showed a steady increase. With a more strategic outreach programme and better marketing of in particular the MSc programme (with e.g. a scholarship programme to start in 2018) we are well positioned to further increase the number of students. We also could put more effort in service teaching, which right now is mostly restricted to the beta-gamma Bachelor programme and the liberal arts programme of the Amsterdam University College.

Rejuvenation/innovation potential: As a result of the many hires during the past year, the age build-up of the institute is now fairly homogeneous: <35 (1), 35-40 (8), 40-45 (6), 45-50 (2), 50-55 (3), 55-60 (0), 60-65 (2). There presently is one vacancy (QuSoft), and if nothing would change, we would probably not be able to hire someone else for the next 5 years. Given how relatively young the staff of the institute is, we do not think this is problematic per se. Moreover, external circumstances are so volatile that it is hard to predict even the near future, and there are several other ways to adjust and innovate the research portfolio of the ITFA.

Finances: Thanks to several recently obtained grants, the financial outlook for the next couple of years is excellent. As almost everywhere, the primary source of funding for PhDs and postdocs consists of external grants. Our past track record gives us confidence for the future, where it is a concern that as our staff becomes more senior, the number of (personal) grants one can apply for decreases. It is therefore great that as IoP we have been able to reserve some money for an internal call for PhD and postdoc positions in 2016, to be repeated again in 2017. We closely monitor (inter)national developments and try to anticipate new funding opportunities as much ahead of time as possible.

Strategic position: Purely curiosity-driven research is facing increasing pressure to become more applied. We have secured several influential positions (membership of the Board of the Science Domain of NWO, membership of the University Research Committee, membership of the Royal Academy and KHMW, involvement in “route 5” of the National Research Agenda, etc.) to make sure the importance of bottom-up curiosity-driven research is continuously emphasized and to gain a strategic advantage in preparing for new funding opportunities before they are officially announced. To emphasize the importance of curiosity-driven research is also an important goal of our outreach programme.

Examples of important **strategic goals and targets** for the present and future are:

- Increase international visibility and reputation of ITFA.
- Benefit from the recent discovery of gravitational waves: strengthen the link between GRAPPA, cosmology, high-energy theory and Nikhef through the intended hire of a gravitational wave astrophysicist and collaboration in the national science agenda. *Faculty search for a joint IHEF/API position with this profile has begun; national science agenda project starts Jan 2018.*
- Realizing a new hire at ITFA through Quantum Software Consortium (quantum control & quantum simulation) *Anticipated sometime in 2018.*
- Investigate possibilities to hire (possibly jointly with IHEF) and Beyond the Standard Model expert in line with a recommendation from our Scientific Advisory Panel. *Will depend on success in future grant applications in e.g. the gravitation program.*
- Develop a more strategic approach to recruiting. *This will be part of the agenda of the next ITFA retreat.*
- Improve HR policy, in particular establish clearer and more transparent goals for career development after tenure. *Strategic personnel plan should be ready early 2018.*
- Unite Theoretical Physics Amsterdam in one strong institute (division) at uni-location, especially for soft matter/bio theory, vs critical mass (i) strengthen the collaboration with the VU soft matter theory group, (ii) strengthen the collaboration with the soft matter experimental group at WZI, and (iii) look for collaborations with other groups at Science Park, in particular at AMOLF and ILLC. *Ongoing discussion with faculties and university boards to see what is and is not possible.*
- Further improve the quality of education, in particular the MSc program and make it comparable to and competitive with programs such as those in Munich and the Perimeter Institute. *Ongoing process, with more grants and better advertising for next year.*
- Ensure that Master and PhD students have a clear view of future possibilities well in advance of finishing. *Brainstorm planned sometime in 2018.*
- Keep on stimulating collaborations with researchers from other groups and other institutes. *Mostly through Delta ITP and IoP internal calls.*

- Diversify sources of external grants to become less dependent on NWO and ERC's *E.g. invest in national science agenda and try to become part of future Simons Center calls.*
- Take a leading role in establishing European networks and collaborations in theoretical physics. *Look into possibilities starting late 2018 starting with e.g. LERU or U21.*
- After the extensive growth of the past years, focus on consolidating current, strong position.
- Maintain high-level of support for grant applications (from colleagues, proof-readers, interview trainer, etc.) and encouragement of the staff to apply for various opportunities; actively scout for funding opportunities. *Ongoing process.*
- Attract more PhD's and postdocs who bring their own funding, attract more high-profile long-term visitors and attract more scientists who take a sabbatical. *Plan to improve website and hope IPA long term visitor program will help get the ball rolling.*
- Realize several professorships by special appointment at ITFA. *After some effort two years ago we will pick this up again next year.*
- Have a more strategic approach to outreach, evaluating the effect of the activities in a quantitative manner and using those results to plan future activities. *Preliminary plan was drafted and will be worked out with expert advice from I. Smeets, professor of Science Communication in Leiden.*

E.2.6 SWOT analysis

Strengths

- The embedding of the ITFA in the IoP and the location at the Science Park near several other physics Institutes (AMOLF, Nikhef, ARCNL).
- The financial situation for the upcoming years.
- The informal governance with little internal hierarchy.
- The professional support staff.
- The large number of talented candidates applying for vacancies at all levels.
- The broad set of advanced courses we are able to offer.
- The proactive way in which the ITFA responds to changes in external circumstances.
- The large number of external collaborations.
- Substantial public visibility.
- Strong international visibility e.g. through the string theory group.

Weaknesses

- The demographic composition of the institute is not optimally balanced.
- The exposure of PhD students and postdocs to career opportunities outside academia is limited.
- The lack of space in the building and the layout of the offices (along a long corridor).
- Diversity in the ITFA is limited.
- HR policies need to be improved and made more transparent, especially regarding the path from associate to full professor.
- The relatively narrow list of possible funding sources.
- The subcritical size of the soft matter group.
- The lack of a materials science and engineering department in the vicinity of UvA.
- Synergy between ITFA, GRAPPA and Nikhef remains somewhat unexplored; not unrelated, some key research areas, such as observational cosmology and beyond the standard model physics, have a very limited presence.

Opportunities

5. International visibility can be improved.
6. The Theoretical Physics MSc track can be made more competitive, similar to programmes at e.g. Munich or the Perimeter Institute.

7. Further strengthen collaborations within and outside UvA with joint projects and joint appointments.
8. Benefit even more from exciting discoveries such as the recent observation of gravitational waves.
9. Effective exploitation of the newly purchased ITFA computing cluster.
10. Take a more strategic approach to outreach.
11. Participation in existing strong networks of theoretical physics institutes in Europe.

- Build a vibrant mathematical physics community in the region.
- Attract more PhDs and postdocs by exploiting (personal) fellowship programmes.
- Attract more high-profile visitors and professorships by special appointment.
- Exploit the strong presence in computational physics after the hiring of Corboz and Lerner.
- Exploit new opportunities for interdisciplinary funding at the national level.
- Build a stronger alumni network, e.g. to strengthen our relations with industry.

Threats

- Increasing pressure on fundamental, curiosity-driven research.
- The lack of increase in national funding for research compared to the increase in student numbers.
- The lack of a tradition or culture of private donations to science.
- Large fluctuations in funding make long-term research planning difficult and lead to situations where research groups become subcritical and lose international competitiveness.

Actions resulting from SWOT

The main things we plan to do to capitalize on the strengths, address the weaknesses, benefit from the opportunities and counter the threats are described above in the strategy and quality, relevance and viability sections. There are certain issues, such as the demographical composition of the institute, the lack of space in the building, the lack of a nearby engineering department, and national politics, which are largely outside our control.

E.2.7 Relevant environmental factors and developments

- The creation of the IoP in 2011 has led to much more interaction and collaboration between IHEF, ITFA and WZI. It also allowed us to hire an institute manager which had a major impact on the level of support and made the institute much more professional. The governance of IoP (lean and mean) works very well in practice and, overall, the creation of the IoP has been a resounding success.
- The move of the Faculty of Science from various buildings to a single new building at the Science Park created a more attractive environment for students and has led to more interactions and collaborations with other institutes. This move has definitely contributed to the growth in student numbers. Unfortunately, the new building turns out to be too small to accommodate the growth in staff and student numbers. This has led to the move of two institutes, KdVI and ILLC, to alternative housing across the road adjacent to the Nikhef building. Still, we are faced with a shortage of office and desk space. We specifically find it difficult to accommodate the Master's students working on their thesis project, and to find appropriate rooms for seminars, workshops and conferences.
- The Sector Plan for Physics and Chemistry from 2009 generated structural additional funding for physics and chemistry and identified research priority areas in each university. In ITFA, this additional funding was mostly used for several of the hires in GRAPPA.
- Both the Faculty of Science and UvA adopted a research priority area (RPA) policy. This led to the possibility to apply for extra structural funding. GRAPPA

is one of the RPA's of the university which successfully applied for such funding in 2011 and QMQI followed in 2015 and both contributed to the further strengthening of these RPA's and a corresponding growth of the ITFA. At a more modest level we also participate in the RPA "Soft Matter" of the faculty.

- As described in Section , the merger of the physics departments of the UvA and VU did not materialize. For the ITFA, this would in particular have had a positive impact for the research in theoretical soft matter/biophysics, and to a lesser extent in the history/philosophy of science, theoretical soft matter/biophysics, and theoretical particle physics. The challenge for the upcoming years will be to still create as much added value as possible within the new situation while preventing negative impact on the joint efforts in teaching.
- The NWO Gravitation Grant scheme was introduced in 2012 to support consortia of researchers for periods of 10 years with substantial funding (~20-30M€). The successful application of the Delta ITP consortium coordinated by ITFA in 2012 has had a major impact on ITFA, and we expect substantial impact from our participation in the successful QSC application of 2017 as well.
- The government seems intent to realign science funding, to some extent, along (i) the national research agenda, (ii) the top sectors, (iii) key enabling technologies and (iv) grand societal challenges. It is hard to predict what all this is going to mean in practice and what the plans of the new government precisely will be. We are actively participating in one of the 25 routes (fundamental constituents of the universe) of the National Research Agenda and are awaiting further developments[7]. Eight routes, including this one, recently obtained an NWO "Startimpuls" grant of 2.5 M€.

[7] While this document was being written, the newly instated government announced its intention to eventually invest an additional 200 M€ in fundamental research annually which will be distributed along the national research agenda and topsectors.

- Closely related, there is an increasing emphasis on broad interdisciplinary research under the assumption (for which we have been unable to find scientific evidence) that true breakthroughs can only be realized by broad interdisciplinary teams of researchers.
- FOM, which was the main funding organization for physics in the Netherlands, ceased to exist at the end of 2016 and became part of NWO, as part of a major overhaul of NWO. In the "new NWO", physics funding is no longer a separate part of the budget and eventually funding will have to be acquired in competition with other disciplines – both a threat and an opportunity.

E.2.8 International position and benchmark

Theoretical physics is an internationally recognized (sub)discipline. There are many universities with centres or institutes for theoretical physics, though the scope of these institutes varies. Sometimes theoretical physicists with a more mathematical profile are part of a mathematics department rather than a physics department. It also often happens that theoretical condensed-matter physics is not part of a separate theoretical physics unit but belong to a group or institute which combines both experimental and theoretical condensed matter physics. Finally, we see that sometimes theoretical centres are created which are not independent institutes but a place for theorists to meet, host workshops, and sometimes offer special fellowships (e.g., the Princeton Centre for Theoretical Physics). In ITFA, we highly value the combination of theoretical condensed-matter and high-energy physics, where there is a substantial amount of cross-fertilization; at the same time we are part of the IoP and adjacent to our experimental colleagues at the WZI. Therefore, at the ITFA we get the best of both worlds.

Some relevant well-known institutions are:

- The institute for Theoretical Physics at Saclay.
- The Arnold Sommerfeld Institute for Theoretical Physics and the LMU in Munich.
- The Rudolf Peierls Centre for Theoretical Physics at Oxford.
- The Department of Applied Mathematics and Theoretical Physics (DAMTP) at Cambridge.
- The Center for Theoretical Physics at Imperial College.
- NORDITA, a joint institute of the Nordic countries in Stockholm.
- The Institute for Theoretical Physics of the ETH.
- The Institute of Cosmos Sciences, University of Barcelona.
- The CERN theory group.
- The ICTP at Trieste.
- The School of Natural Sciences of the IAS, Princeton.
- The aforementioned Princeton Center for Theoretical Science.
- The Kavli Institute for Theoretical Physics at UCSB.
- The Perimeter Institute at Waterloo, Canada.
- The Simons Center at Stony Brook.
- Harvard Center for the Fundamental Laws of Nature and its Black Hole Initiative.
- The Stanford Institute for Theoretical Physics.
- The Kadanoff Center for Theoretical Physics at the University of Chicago.
- The Walter Burke Institute for Theoretical Physics at Caltech.
- The Berkeley Center for Theoretical Physics.

Looking at the above list, we notice that several centres combine research with a continuous inflow of visitors for workshops and/or longer scientific programmes. This is not a realistic ambition for the ITFA at the moment, as we have neither the resources nor the infrastructure right now, and with e.g. the Lorentz Centre at Leiden we already have a good national facility for shorter workshops. We do however have the newly invigorated IPA visitors' programme, with 4 long-term visitors coming in one year, and more to come.

The institutes that are most similar to us in Europe are probably the ones in Munich, Copenhagen, Cambridge and the ETH, and in North America the Perimeter Institute, Chicago, Stanford and Caltech. The institutes for theoretical physics in Leiden and Utrecht were not included in the above list, because with Delta ITP we have chosen to position ourselves as a single entity rather than three competing institutes. Our Unique Selling Point, compared to these other institutes, is the combination of (i) the broad scope of our research, (ii) the close integration of different types of research, (iii) being part of a university and embedded in a student community, (iv) the international character of our institute, (v) the convenient location, (vi) our position in a broad science faculty and among many other scientific institutes at Science Park, and finally (vii) the city of Amsterdam. In practice, it is our experience (from e.g. postdoc and staff hires) that it is hard to compete with the top US institutions, but that we are quite competitive in Europe in most fields, and would like to position ourselves right now in the top 5 theoretical institutes in Europe and top 10 worldwide.

E.3 PhD programme

The general policies set by universities are described in Section .

E.3.1 Context, supervision and quality assurance

Besides the two formal supervisors (either two promotors or a promotor and a co-promotor), IoP-policy prescribes that an independent supervisor from a different research group is assigned to each PhD student at the start of each PhD. This independent supervisor is a contact person for both the PhD student and the main supervisor(s), should a problem arise between the two. The presence of the second supervisor during the annual interviews ensures that the PhD programme is also reviewed from a wider perspective. Involving an independent supervisor in the PhD programme is intended to prevent stagnation of the project, which potentially results in delays. The independent supervisor was introduced in 2013 and is generally perceived by PhD students as well as staff as a valuable way both for quality assurance and improvement of well-being of PhD students.

Besides formal annual assessment and progress meetings, the format of the day-to-day supervision is mostly left to the supervisor(s) and the PhD student. In case of problems, the PhD student can request help from the second independent supervisor. The IoP PhD/postdoc council as well as the IoP support office also play a pivotal role here: they are often the first ones to detect a possible problem, and know the appropriate channels to find help for individual PhD students with issues. To help new PhD students get to know other members of the institute, the IoP PhD/postdoc council frequently organizes social activities for and a monthly lunch seminar.

During the annual reviews of ITFA staff with the head of the ITFA, the status and progress of all PhD students is always discussed and in case of a possible delay the cause and usually a course of action to limit the delay are discussed and included in the report of the annual review.

E.3.2 Courses for PhD candidates

The partially mandatory “soft skills” programme organized by the Faculty of Science is described on gss.uva.nl/current-phds/skills-development/faculty-level/faculty-program.html. PhD students employed by FOM (now called NWO-I) have a separate set of mandatory/optional courses described at www.nwo-i.nl/en/personnel/information-for-phd-students-and-postdocs/special-courses-for-trainee-researchers/.

In many cases, additional programmes are tailor-made for the PhD students. They are offered the possibility to independently identify relevant course modules, for which the IoP can supply a financial contribution in case the research group cannot cover this.

The ITFA is member of a national research school, the Dutch Research School for Theoretical Physics (DRSTP). Students are registered in the school and their Training and Supervision Plans submitted. The DRSTP offers two two-weeks schools annually, one in theoretical high-energy physics and one in statistical/condensed matter theory. PhD students are expected to attend one of these schools each year during the first two years of their PhD (web.science.uu.nl/drstp/Postgr.courses/aiocurs.html). String theory PhD students usually attend an intense 9-week programme during the first months of their appointment, which is organized together with Brussels, Paris and Gevena (://www.solvayinstitutes.be/html/doctoral.html). Also, the Delta ITP offers advanced courses for advanced Master’s students and PhD students (web.science.uu.nl/drstp/DeltaITP/deltaitp.html). Besides these local possibilities, PhD students usually attend a few individually selected international schools, workshops and conferences. Besides providing specialized education, these schools also allow PhD students to build a national network early on in their careers. For this, the PhD council of the school organizes among others an annual PhD day.

E.3.3 Selection and admission procedures

Vacancies in theoretical physics worldwide – at all levels including PhD positions – typically follow a fixed annual cycle: they advertised in the Fall, aiming at a starting date in September. The selection of the candidates is done by the supervisor(s) and can include a visit of a few top candidates or a Skype interview. The involvement of other staff members in the selection procedure is strongly encouraged. The annual hiring cycle allows for pooling vacancies together, leading to large numbers (>100) of applications – in particular for GRAPPA and the string theory group. Candidates are selected in an annual event where the top candidates are invited for a visit, give a seminar, and have individual discussions with several group members.

E.3.4 Supervision of PhD candidates and guidance to the labour market

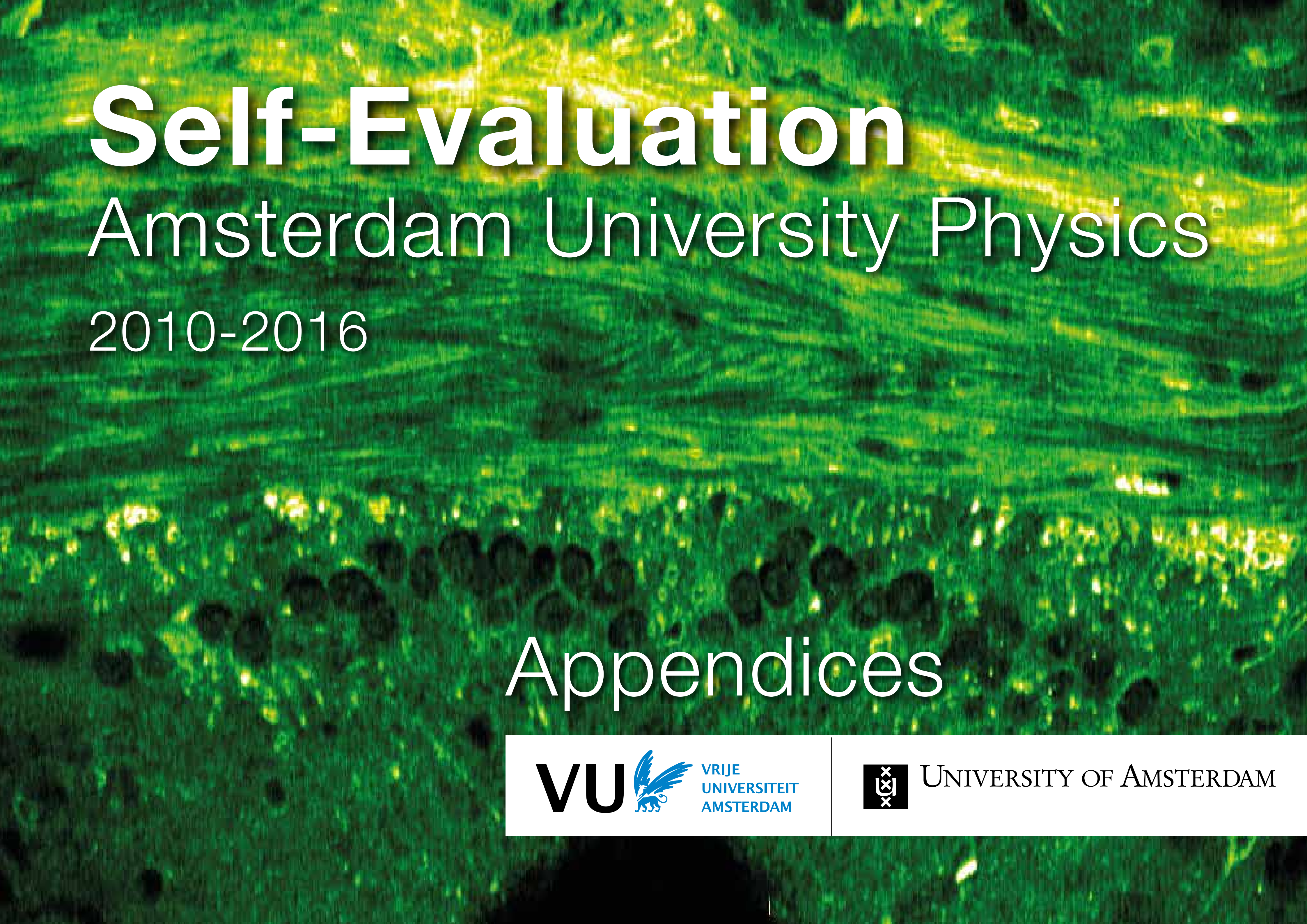
General policies are described in Section . On top of that, the "Theory in Practice" workshop offered by Delta ITP allows PhD students to get acquainted with a variety of analytics-driven organizations in the (semi-) private sector, to meet a diverse group of former physics graduates and learn how they shaped their careers, and increase their hands-on problem solving skills while working in a team.

E.3.5 Duration and success rates

As the numbers in Appendix F.6.4 show, roughly half of our PhD students complete their manuscript within 4 years, which is a very good result. Sometimes the 4 years are exceeded for purely logistical reasons, as are no defences from mid-July until early September. Of the 8 PhD students who exceeded the 4 years but finished within 5 years 6 finished within 4.5 years. Causes of delay or (rare) dropout vary. There are cases where there are insufficient results for a PhD thesis, sometimes the writing of the thesis itself takes much more time than anticipated, sometimes personal circumstances of PhD student and/or supervisor(s) give rise to delays. As described under and , we have introduced several mechanisms whereby we try to identify potential delays as early as possible and try to prevent or minimize them, and we expect a further decrease in the average duration for the upcoming years. The more detailed breakdown in Appendix F.6.4 indeed already shows a gradually improving trend in duration and success rates over the evaluation period.

E.3.6 Exit numbers to various sectors

The pie chart in Appendix F.6.4 is based on a total of 34 PhDs in ITFA and gives an impression of the various sectors where PhDs find positions immediately after their PhD. More than 60% remained in academia. To the best of our knowledge, none of our former PhD students are unemployed right now.



Self-Evaluation

Amsterdam University Physics

2010-2016

Appendices

VU VRIJE UNIVERSITEIT AMSTERDAM

UNIVERSITY OF AMSTERDAM

F. Appendices

F.1 Glossary

AAA	Amsterdam Academic Alliance, the framework used by UvA and VU for their joint activities
AAA Fellowships	Fellowship programme to strategically create new staff positions within joint initiatives by UvA and VU departments, carried out under the AAA umbrella
ACE	Amsterdam Centre for Enterpreneurship
AIMMS	Amsterdam Institute for Molecules, Medicines and Systems, an interdisciplinary research institute at the VU
ALW	'Aard- en Levenswetenschappen', the (former) Earth and Life Science domain of the NWO, since 2017 part of NWO's Science Domain
AMC	Academic Medical Centre of UvA
AMEP	Advanced Matter and Energy Physics, an experimental physics track in the MSc programme Physics and Astronomy
AMOLF	NWO institute for physics of functional complex matter, located at Amsterdam Science Park
API	Anton Pannekoek Institute for Astronomy (UvA astronomy institute)
APRIL	Amsterdam Physics Research and Innovation Labs, a programme aimed at boosting valorisation initiatives by the Amsterdam knowledge institutes with financial support by the Municipality of Amsterdam
ARCNL	Advanced Research Centre for Nanolithography, a 2014-founded collaboration between ASML, UvA, VU and NWO, located at Amsterdam Science Park
AUC	Amsterdam University College, a joint educational institute of UvA and VU teaching a Liberal Arts and Sciences programme
CW	'Chemische Wetenschappen', the (former) Chemical Sciences domain of NWO, since 2017 part of NWO's Science Domain
Delta ITP	Delta Institute for Theoretical Physics – an NWO Gravitation consortium of UvA, Leiden and Utrecht, awarded in 2013
ECN	Energy research Centre of the Netherlands, located in Petten
EC/ECTS	European Credit (Transfer and Accumulation System); one academic year corresponds to 60 ECTS credits
ERC	European Research Council

FET	Future and Emerging Technologies, an EU funding instrument for collaborative grants
FOM	'Stichting Fundamenteel Onderzoek der Materie', Foundation for Fundamental Research on Matter, the former NWO daughter organisation that nationally funded physics research and owned research institutes such as AMOLF and Nikhef. Since 2017, FOM is converted into NWO-I; the funding of physics research is now organisationally embedded within NWO's Science Domain.
GRAPPA	Gravitation and AstroParticle Physics; RPA / centre of excellence at UvA
HFSP	Human Frontier Science Programme, an international programme that funds frontier research into complex biological systems
HIMS	Van 't Hoff Institute for Molecular Sciences (UvA chemistry)
IHEF	Institute of High Energy Physics ('Fysica'), a division of UvA's IoP, but within this document generalized to include Astro-Particle physics section at VU
ILLC	Institute for Logic, Language and Computation (UvA, joint between Faculties of Science and Humanities)
IoP	Institute of Physics (UvA)
IPA	Institute of Physics and Astronomy, working title for the joint institute to be formed from UvA's Institute of Physics, the VU Department of Physics and Astronomy and UvA's Anton Pannekoek Institute for Astronomy
IPP	Industrial Partnerships Programme, a FOM/NWO granting instrument requiring 50% in cash contributions from private/industrial partners
ITFA	Institute for Theoretical Physics ('Fysica') Amsterdam, a division of UvA's IoP
KdVI	Korteweg-de Vries Institute for Mathematics (UvA)
KHMW	'Koninklijke Hollandsche Maatschappij der Wetenschappen', the Royal Holland Society of Sciences and Humanities
KNAW	'Koninklijke Nederlandse Akademie van Wetenschappen', the Royal Netherlands Academy of Arts and Sciences (KNAW)
LaserLaB	Institute for Lasers, Life sciences and Biophotonics Amsterdam, an interdisciplinary research institute of VU, VUmc, AMC and UvA. Within this evaluation, LaserLaB refers to the combined sections of the VU Department of Physics and Astronomy that together form the core of LaserLaB.
MNW/MNS	'Medische Natuurwetenschappen' and Medical Natural Sciences are BSc and MSc programmes at the VU to which VU Physics and Astronomy staff contribute
NFI	Netherlands Forensic Institute
NICAS	Netherlands Institute for Conservation, Art and Science, an interdisciplinary institute of UvA, TU Delft, the Rijksmuseum, the Cultural Heritage Agency of the Netherlands (RCE), and NWO
Nikhef	National Institute for Subatomic Physics, a former FOM institute now residing under the NWO-I flag. Nikhef is a collaboration between NWO and UvA, VU, Radboud University Nijmegen, Utrecht University and Groningen University, located at Amsterdam Science Park.
NNV	'Nederlandse Natuurkundige Vereniging', Netherlands Physical Society

NTvN	'Nederlands Tijdschrift voor Natuurkunde', Dutch Journal for Physics
NWA	'Nationale Wetenschapsagenda', National Research Agenda, see wetenschapsagenda.nl
NWO	'Nederlandse Organisatie voor Wetenschappelijk Onderzoek', Netherlands Organisation for Scientific Research, the national funding agency for scientific research
NWO Gravitation	NWO funding scheme of typically M€15+ grants aimed at stimulating research by consortia of Dutch top researchers
NWO Veni/Vidi/ Vici	NWO funding schemes in for personal grants of order 250k€, 800k€ and 1500k€, respectively.
NWO-I	The new Institutes organisation of the NWO that comprises (a.o.) AMOLF, ARCNL and Nikhef; NWO-I organisationally largely overlaps with the former FOM organisation.
RPA	Research Priority Area (of UvA)
SBI	Science, Business and Innovation, a BSc and MSc programme at the VU to which VU Physics and Astronomy staff contribute
Sector Plan	Sector Plan for Physics and Chemistry, a national initiative of the Dutch physics and chemistry research communities at universities with their main funding agencies (FOM and NWO-CW) to catalyse additional investments from the science ministry of 10M€ per year per discipline.

SEP	Standard Evaluation Protocol, quality assurance protocol formulated and endorsed by the VSNU, KNAW and NWO for evaluation of Dutch universities as well as NWO and KNAW institutes
Solardam	AAA-funded initiative of UvA, VU, AMOLF and ECN with a multidisciplinary research program to harvest energy from the sun by generating electricity and fuel through combinations of photovoltaics, photocatalysis and photosynthesis
SRON	Netherlands Institute for Space Research, located in Utrecht (but currently in a tender procedure to relocate to the vicinity of another Dutch university; UvA and VU jointly put in a bid)
STW	Technology Foundation STW, after the 2017 NWO transition reorganised into NWO Domain Applied and Engineering Sciences
TC	Technology Centre, UvA Faculty of Science department for workshop support in the fields of mechanical construction, electronics and software
TNO	Netherlands Organisation for applied scientific research
TT, TT'er	Tenure track, tenure tracker
TU	Technical University, of which four exist in the Netherlands: Delft (TU Delft), Eindhoven (TU/e), and Twente (UT)
QM&QI	Quantum Matter and Quantum Information, RPA of UvA comprising groups from WZI, ITFA, ILLC and KdVI
QSC	Quantum Software Consortium – an NWO Gravitation consortium of QuSoft plus groups from Leiden and QuTech/TUDelft, awarded in 2017

QuSoft	Dutch research centre for quantum software, launched by UvA, VU, and CWI and structurally funded through UvA's RPA QM&QI
UvA	University of Amsterdam
VSNU	'Vereniging van Samenwerkende Nederlandse Universiteiten', the Association of research universities in the Netherlands
VU	Vrije Universiteit
VUmc	VU Medical Center
WZI	Van der Waals-Zeeman Institute for experimental physics, a division of UvA's IoP

F.2 Research staff composition

This section contains the developments of staff size of the four research units. Note that the numbers reported are full fte's, i.e. not restricted to research time.

F.2.1 LaserLaB

	2010	2011	2012	2013	2014	2015	2016
Scientific staff	17.7	18.2	20.6	23.0	24.7	23.0	21.2
- Full professors	7.5	8.1	7.0	11.0	10.9	10.2	10.5
- Associate professors ('UHD')	7.0	7.0	8.8	6.1	7.9	8.0	7.9
- Assistant professors ('UD')	2.0	2.0	4.0	5.0	4.0	3.8	2.8
Postdocs	17.9	28.5	30.6	33.4	28.7	32.4	34.2
PhD students	22.4	26.7	35.1	31.1	35.7	39.2	39.3
Technical support staff	3.0	3.7	3.9	1.1	2.9	3.7	4.0
Total staff	**59.8**	**76.0**	**89.4**	**87.7**	**90.1**	**97.3**	**98.7**

F.2.2 Van der Waals-Zeeman Institute

	2010	2011	2012	2013	2014	2015	2016
Scientific staff	12.4	12.3	12.8	13.4	15.7	15.4	16.9
- Full professors	5.4	5.4	5.2	4.9	6.1	7.7	7.4
- Associate professors ('UHD')	4.0	4.3	6.0	6.0	5.9	4.0	4.0
- Assistant professors ('UD')	3.0	2.6	1.6	2.5	3.6	3.8	4.3
- Teaching staff							1.2
Postdocs	8.0	12.5	14.5	12.0	11.9	14.5	15.6
PhD students	22.0	23.2	27.2	30.1	35.3	37.5	41.0
Technical support staff	3.6	2.0	2.0	2.0	3.0	3.6	3.8
Total staff	**46.0**	**50.0**	**56.5**	**57.4**	**65.8**	**71.1**	**77.3**

F.2.3 Institute for High-Energy Physics

	2010	2011	2012	2013	2014	2015	2016
Scientific staff	11.4	10.8	13.1	14.4	14.6	14.4	15.6
- Full professors	4.6	5.6	7.1	7.4	8.2	9.2	9.4
- Associate professors ('UHD')	2.0	3.2	4.0	5.1	4.5	3.2	3.0
- Assistant professors ('UD')	3.8	2.0	2.0	2.0	2.0	2.0	3.3

	2010	2011	2012	2013	2014	2015	2016
- Teaching staff	1.0						
Postdocs*)	2.0	1.9	1.3	2.6	4.3	4.3	5.3
PhD students*)	4.8	3.0	3.0	0.0	2.5	5.7	7.4
Total staff	**18.1**	**15.6**	**17.3**	**17.0**	**21.4**	**24.4**	**28.3**

*) The numbers of PhD and postdoc fte's contain only employees of UvA and VU. Since at Nikhef these are most often employed by NWO and working on one of Nikhef's research programmes, the assignment to either UvA or VU is ambiguous. Thus, the fte numbers for PhDs and postdocs above are an underestimate.

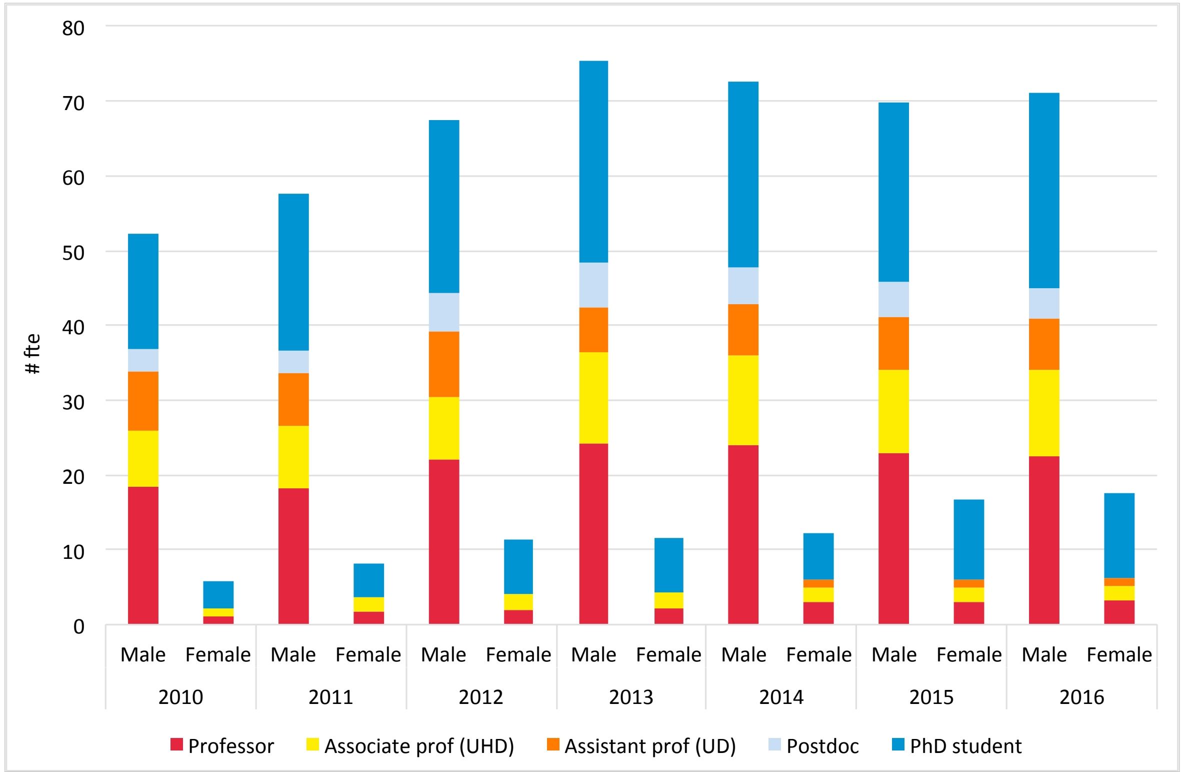
F.2.4 Institute for Theoretical Physics

	2010	2011	2012	2013	2014	2015	2016
Scientific staff	11.8	13.5	14.3	12.1	17.5	19.7	21.9
- Full professors	6.9	7.2	7.6	6.5	7.3	6.8	7.7
- Associate professors ('UHD')	4.7	4.1	3.7	2.2	3.8	4.6	5.6
- Assistant professors ('UD')		2.0	2.8	3.3	6.3	8.3	8.6
- Teaching staff	0.2	0.2	0.2	0.2	0.2		
Postdocs	11.2	9.2	12.8	16.7	20.2	19.3	19.9
PhD students	13.4	16.0	23.2	24.5	26.7	35.0	34.1
Total staff	**36.5**	**38.6**	**50.2**	**53.3**	**64.5**	**74.0**	**75.9**

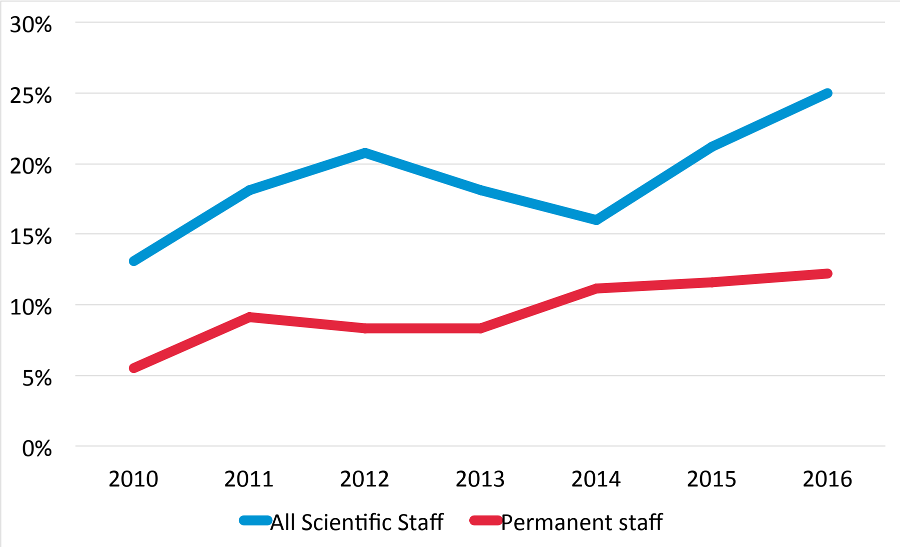
F.2.5 Diversity

F.2.5.1 VU Physics and Astronomy

Gender diversity



Development of the male/female balance in all staff positions at the VU Department of Physics and Astronomy



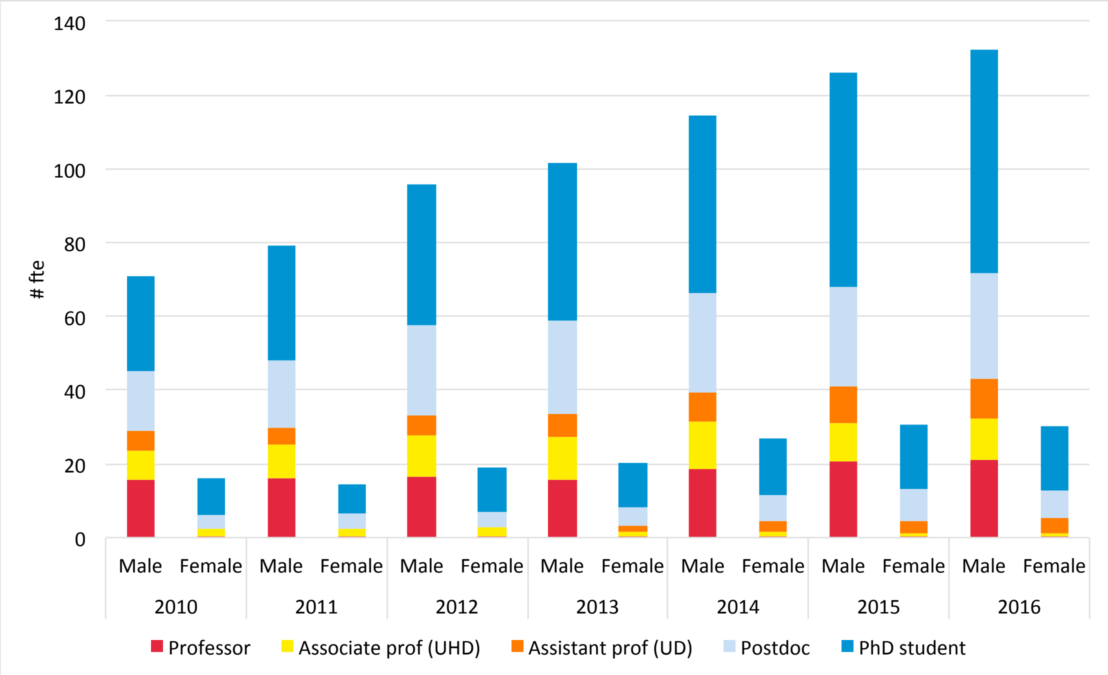
Development of the percentage of female staff in the permanent and overall scientific staff at the VU Department of Physics and Astronomy.

Cultural diversity

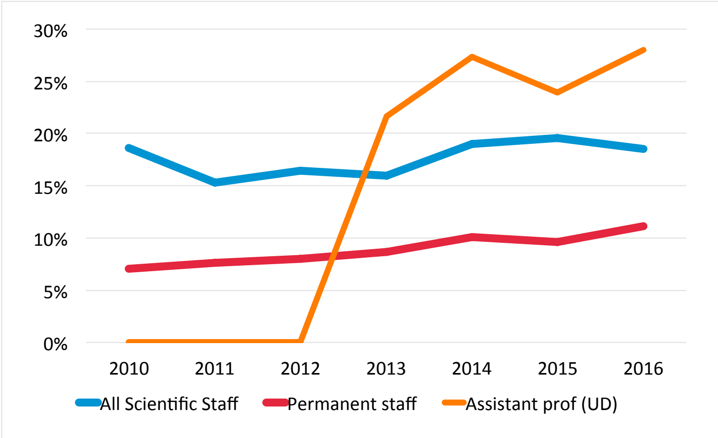
Year	Non-Dutch fraction of staff (based on fte's)	Number of nationalities
2010	36%	14
2011	40%	14
2012	44%	12
2013	42%	13
2014	43%	17
2015	49%	20
2016	44%	20

F.2.5.2 UvA Institute of Physics

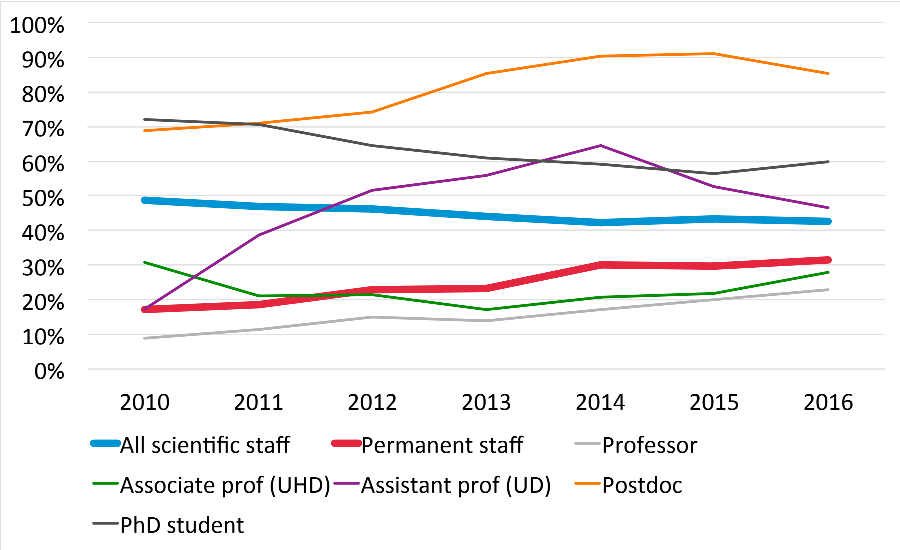
Gender diversity



Development of the male/female balance in all staff positions at the UvA Institute of Physics.



Development of the percentage of female staff in the permanent and overall scientific staff and at the Assistant Professor (UD) level at UvA's Institute of Physics.



Development of the percentage of non-Dutch scientists at UvA's Institute of Physics.

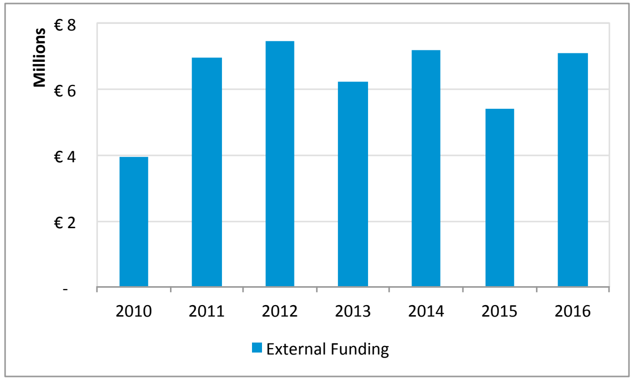
Cultural diversity

Year	Non-Dutch fraction of staff (based on fte's)	Number of nationalities
2010	49%	23
2011	47%	27
2012	46%	35
2013	44%	36
2014	42%	32
2015	43%	36
2016	43%	37

F.3 Funding

F.3.1 VU Physics and Astronomy

	2010	2011	2012	2013	2014	2015	2016
Funding	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**
Direct funding	28.7 (42%)	27.6 (31%)	27.2 (32%)	29.0 (40%)	35.2 (34%)	39.0 (50%)	41.2 (47%)
Research grants	27.2 (36%)	31.3 (40%)	38.0 (44%)	38.0 (37%)	39.4 (40%)	36.3 (28%)	33.9 (24%)
Contract research	13.8 (22%)	22.9 (29%)	31.9 (24%)	31.9 (23%)	27.2 (26%)	36.1 (22%)	37.3 (29%)
Total funding	**69.6**	**81.69**	**97.13**	**96.76**	**101.78**	**111.46**	**112.3**
Expenditure							
Personnel costs	M€ 4.91	M€ 5.57	M€ 6.92	M€ 7.66	M€ 7.99	M€ 8.52	M€ 8.65
Other costs	M€ 1.98	M€ 4.87	M€ 3.89	M€ 2.47	M€ 3.71	M€ 2.63	M€ 5.52
Total expenditure	**M€ 6.89**	**M€ 10.43**	**M€ 10.81**	**M€ 10.14**	**M€ 11.7**	**M€ 11.14**	**M€ 14.17**



Gross turnover of external funding of the Department of Physics and Astronomy 2010-2016. Note the gross turnover can fluctuate between years due to large investments but an overall increase in turnover can be observed.

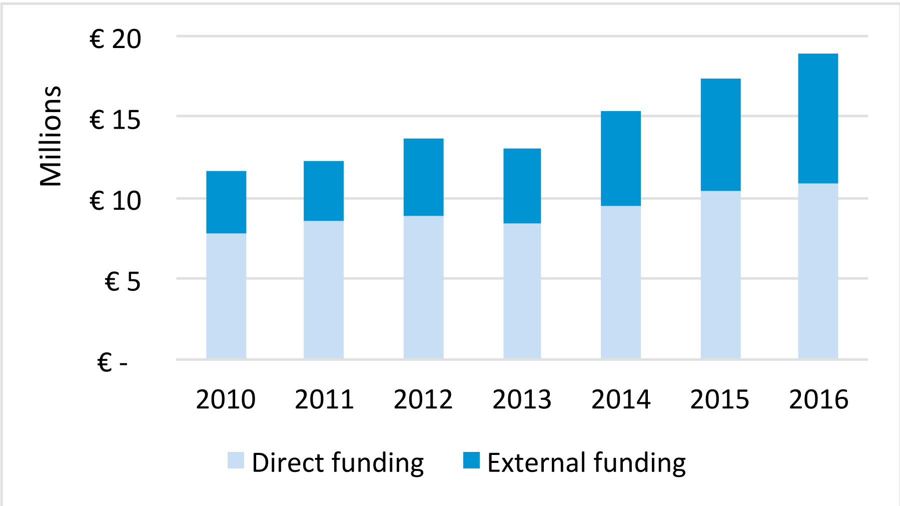
F.3.2 UvA Institute of Physics

	2010	2011	2012	2013	2014	2015	2016
Funding	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**	**# fte (%)**
WZI							
Direct funding	21.1 (46%)	18.7 (37%)	20.0 (35%)	24.4 (40%)	31.6 (47%)	33.1 (45%)	33.9 (43%)
Research grants	24.2 (52%)	30.8 (61%)	34.7 (62%)	33.2 (54%)	30.0 (44%)	31.7 (43%)	32.3 (40%)
Contract research	1.0 (2%)	1.3 (3%)	1.7 (3%)	3.5 (6%)	6.2 (9%)	8.6 (12%)	13.5 (17%)
Total funding	**46.3**	**50.9**	**56.5**	**61.1**	**67.8**	**73.4**	**79.8**
IHEF (IoP)							
Direct funding	11.4 (82%)	10.0 (76%)	10.1 (74%)	12.1 (100%)	12.1 (92%)	12.2 (86%)	12.8 (73%)
Research grants	2.5 (18%)	2.5 (19%)	3.6 (26%)	0.0 (0%)	1.0 (8%)	2.0 (14%)	4.7 (27%)
Contract research	0.0 (0%)	0.6 (5%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0 (0%)
Total funding	**13.9**	**13.2**	**13.7**	**12.1**	**13.1**	**14.2**	**17.5**
ITFA							
Direct funding	14.4 (38%)	15.7 (40%)	19.6 (37%)	15.1 (29%)	18.6 (31%)	20.3 (29%)	20.8 (28%)
Research grants	11.0 (29%)	20.3 (52%)	25.1 (48%)	27.8 (53%)	28.7 (48%)	36.1 (51%)	41.7 (57%)
Contract research	12.3 (33%)	3.1 (8%)	7.6 (14%)	9.8 (19%)	12.7 (21%)	14.7 (21%)	11.1 (15%)
Total funding	**37.7**	**39.1**	**52.2**	**52.7**	**60.0**	**71.0**	**73.6**
Institute of Physics							
Direct funding	46.9 (48%)	44.5 (43%)	49.7 (41%)	51.6 (41%)	62.3 (44%)	65.6 (41%)	67.5 (40%)
Research grants	37.7 (38%)	53.7 (52%)	63.5 (52%)	61.0 (48%)	59.6 (42%)	69.8 (44%)	78.7 (46%)

	2010	2011	2012	2013	2014	2015	2016
Contract research	13.3 (14%)	5.0 (5%)	9.3 (8%)	13.3 (11%)	18.8 (13%)	23.2 (15%)	24.7 (14%)
Total funding	**97.9**	**103.2**	**122.4**	**125.9**	**140.8**	**158.7**	**170.9**
Expenditure (Institute of Physics)							
Personnel costs	M€ 4.65	M€ 4.2	M€ 4.98	M€ 5.39	M€ 6.8	M€ 7.83	M€ 8.44
Other costs	M€ 4.35	M€ 4.19	M€ 5.69	M€ 5.75	M€ 7.32	M€ 7.45	M€ 8.08
Total expenditure	**M€ 9.01**	**M€ 8.38**	**M€ 10.67**	**M€ 11.15**	**M€ 14.12**	**M€ 15.27**	**M€ 16.52**

As mentioned in Appendix , PhD and postdocs at IHEF cannot be unambiguously assigned to UvA (or VU) and are largely excluded from the above table. Thus, the fte numbers on research grants and contract research for IHEF and IoP are an underestimate.

Expenditures are administrated and shown at the IoP-level. Because of the full-cost accounting model used at UvA, overhead costs that are in fact linked to personnel costs are included under 'other costs'.



Development of the direct and external funding of research at UvA's Institute of Physics. Externally funded projects in which IHEF staff are involved are not included in this graph. The ratio of direct and external funding is influenced by the full-cost accounting scheme currently in place at UvA, in which overhead costs have to be covered from the direct funding budget.

F.4 Output indicators

The tables below contain the quantitative results connected to the performance indicators introduced in the various research units. Since the performance indicators are specific for each research unit, the tables are not uniformly presente

F.4.1 LaserLaB

Scientific Excellence

	2010	2011	2012	2013	2014	2015	2016	Total
Atoms, Molecules, Lasers								
# Publications	35	32	45	35	41	32	32	252
# PhD theses	2	3	1	2	4	5	3	20
Physics of Living Systems								
# Publications	22	30	29	34	29	25	38	207
# Patents		1		2				3
# PhD theses		4	2	4	4	4	5	23
Biophysics Photosynthesis/Energy								
# Publications	35	54	30	35	44	45	34	277
# Patents		1						1
# PhD theses	3	3	1	2		1	4	14
Biophotonics and Medical Imaging								
# Publications	14	14	42	24	14	30	23	161
# PhD theses				1	2	1		4
Photo Conversion Materials								
# Publications	19	11	10	14	23	23	9	109
# PhD theses	2	1		1		3		7
Total Publications	**125**	**141**	**156**	**142**	**151**	**155**	**136**	**1006**
Total PhD theses	**7**	**11**	**4**	**10**	**10**	**14**	**12**	**68**
Total Patents		**2**		**2**				**4**

Earning Power

Year awarded	Project	Title	Contract Sum
2010	NWO Vidi Frese	Designing and redesigning of photosynthesis	€ 800.000
2010	NWO Veni Berera	The regulation of photosynthesis	€ 250.000
2010	ERC Advanced Grondelle	The dynamic protein matrix in photosynthesis: from disorder to life	€ 2.166.000
2010	NWO Veni Witte	Imaging living neurons with a table-top X-ray microscope	€ 250.000
2010	NWO Vici de Boer	Minimally invasive optical diagnostics in medicine	€ 1.500.000

2010	NWO Veni De Groot	3D Tumor Imaging by Self Interference Fluorescence Endoscopy	€ 250.000
2010	NWO Veni Heller	Rapid DNA replicators nabbed	€ 250.000
2010	ERC Starting Wuite	PhysGene - Dissecting a minimal genome: a physical investigation of DNA transactions in mitochondria	€ 1.472.712
2011	NWO Vidi Knoop	Giant few-body states probed with ultracold atoms	€ 800.000
2011	NWO Vici Croce	Harvesting the sun....safely	€ 1.500.000
2011	NWO Veni Oort	Mapping photosynthetic energy migration in relation to stress with novel microscopies	€ 250.000
2011	ERC Consolidator Croce	Thylakoid membrane in action: acclimation strategies in algae and plants	€ 1.696.961
2011	ERC Proof of Concept Iannuzzi	Small but many: scalability to volume production in fiber-top technology	€ 148.000
2011	NWO Vici Peterman	Intracellular-traffic monitoring in living animals with single-motor resolution	€ 1.500.000
2012	NWO Vici Kennis	Shedding light on the optogenetics toolbox	€ 1.500.000
2012	NWO Vidi Koelemeij	SuperGPS through optical networks	€ 800.000
2013	NWO Veni Kloz	Pioneering development of frequency domain two-dimensional Femtosecond stimulated Raman spectroscopy - automated mapping of intramolecular motions and intermolecular interactions between proteins and carotenoids during biological activity	€ 250.000
2013	NWO Vidi Roos	Boarding cells by imaging viral nanopirates	€ 800.000
2013	ERC Consolidator Iannuzzi	Micromachined optomechanical devices: looking at cells, tissues, and organs … with a gentle touch.	€ 1.999.221
2014	ERC Proof of Concept Grondelle	Extracting Super-Resolution from classical fluorescence microscopy	€ 150.000
2015	ERC Advanced Ubachs	Probing Physics beyond the standard model from molecules	€ 2.500.000
2015	H2020 FET Open Wuite	Super-resolution visualisation and manipulation of metaphase chromosomes	€ 1.054.000

2015	ERC Proof of Concept Wuite	Launching acoustic force spectroscopy - unlocking the potential of biomolecular	€ 150.000
2015	ERC Starting Grant Witte	High-resolution microscopy without lenses: a new generation of imaging technology	€ 1.500.000
2016	ERC Advanced Eikema	The proton size puzzle: testing QED at extreme wavelengths	€ 2.497.664

Valorisation

In the last years, four start-up companies have been founded by LaserLaB researchers.

- **Optics11** (www.optics11.com), co-founded by Davide Iannuzzi in 2011. Optics 11 builds optical fibre sensing systems, based on the fibre interferometry and micromanufacturing technology originally developed in Iannuzzi's lab within LaserLaB. Optics11 specializes in fast and lean product development, enabled by their skills in fibre optics, analogue and digital electronics, software, micro-manufacturing, mechanics and mechatronics. Products include:
    - **Piuma** and **Chiaro**, instruments to measure micromechanical properties such as cell & tissue mechanics, and hydrogel stiffness.
    - **DeltaSens** and **ZonaSens**, instruments for remote sensing based on optical fibres with high sensitivity, bandwidth, small dimensions and cost effectiveness.

  In 2016, Value Creation Capital invested in Optics11 through its TechnoNanoFund. Optics11 is housed in the W&N building of VU (same building as LaserLaB) and currently employs 21 people.

- **LUMICKS** (www.lumicks.com), co-founded by Gijs Wuite, Erwin Peterman and LaserLaB alumnus Andrea Candelli in 2014. LUMICKS designs, builds and sells instrumentation for single-molecule studies, based on the optical tweezers, single-molecule fluorescence and acoustic force spectroscopy technologies developed in the Physics of Living Systems section within LaserLaB. LUMICKS provides ready-to-use single-molecule instrumentation that allows researchers in the life sciences to focus on their experiments and breakthrough science. Current products include:
    - **C-trap™** combines optical tweezers, confocal microscopy or STED nanoscopy (**SuperC-trap™**) and an advanced microfluidics system in an integrated and correlated way. C-Trap™ is capable of live, simultaneous and correlative visualization and manipulation of molecular interactions such as DNA-protein interactions with sub-pN force and sub-nm position resolution.
    - **AFS™** uses acoustic waves to exert forces from sub-pN to hundreds of pNs on thousands of biomolecules (e.g. DNA, RNA, proteins) or cells in parallel, with sub-ms response time and inherent stability.

  LUMICKS currently employs 30+ people and is housed in the W&N building of VU (same building as LaserLaB).

- **OPNT** (www.opnt.nl), co-founded by Jeroen Koelemeij in 2014. The mission of OPNT is to make state-of-the-art solutions available to businesses in need of accurate timing, offering reliable and affordable solutions for state-of-the-art network timing, independent of GPS timing. Technology is based on optical time and frequency distribution originally developed in the Atoms, Molecules & Lasers section of LaserLaB. OPNT's unique technology provides any exist-

ing optical network with a unique synchronization feature which distributes a uniform time base – and with an accuracy far beyond GPS timing, allows network synchronization and data time stamping at an unprecedented accuracy level, and opens the door to future terrestrial navigation and positioning systems with performance and reliability surpassing that of any satellite-based positioning system. Applications include fast 4G mobile internet, reliable time stamping of data and financial transactions all over the world, and synchronization of electric power plants for reliable energy supply.
OPNT has received investments from KPN Ventures and Cottonwood Technology Funds and is housed in the VU W&N building (same building as LaserLaB).

- **Tritos Diagnostics** (www.tritosdiagnostics.com), co-founded by Marloes Groot in 2017. Tritos Diagnostics uses the non-linear microscopy methods based on third and second harmonics generation originally developed in the lab of Groot in LaserLaB and has as mission to further advance them into clinical tools. The vision of the company is to employ these label-free, micro-meter resolution imaging technologies for intra-operative, real-time pathological diagnosis, for example for the recognition of tumour boundaries during brain surgery.
  Tritos Diagnostics is housed in the VU W&N building.

F.4.2 Van der Waals-Zeeman Institute

		2010	2011	2012	2013	2014	2015	2016	Total
Hard Condensed Matter	# Publications	19	16	13	12	13	16	31	**120**
	# Top publications	3	5	4	5	3	3	8	**31**
	% Top publications	16%	31%	31%	42%	23%	19%	26%	**26%**
	# PhD degrees	3	3	5	3	5	3	6	**28**
	Avg. H-index PI's (min, max)								**32 (17 - 47)**
	# Conf./workshops organized								**13**
	# Invited lectures								**102**
	# Awarded grants	3	2	6	1	1	1	2	**16**
	Awarded grant vol. (k€)	627	361	2464	274	516	626	417	**5285**

		2010	2011	2012	2013	2014	2015	2016	Total
Soft Matter	# Publications	14	11	16	21	15	25	32	**134**
	# Top publications	6	2	4	9	3	4	4	**32**
	% Top publications	43%	18%	25%	43%	20%	16%	13%	**24%**
	# PhD degrees	1	3	4	7	5	5	4	**29**
	Avg. H-index PI's (min, max)								**31 (12 - 62)**
	# Conf./workshops organized								**6**
	# Invited lectures								**86**
	# Awarded grants	4	6	4	5	1	1	10	**31**
	Awarded grant vol. (k€)	880	1822	1023	579	1500	250	1813	**7866**

		2010	2011	2012	2013	2014	2015	2016	Total
Quantum Gases and Quantum Information	# Publications	13	5	4	6	4	4	11	**47**
	# Top publications	4	0	0	0	0	3	2	**9**
	% Top publications	31%	0%	0%	0%	0%	75%	18%	**19%**
	# PhD degrees	2		4	2	2	2	2	**14**
	Avg. H-index PI's (min, max)								**27 (22 - 31)**
	# Conf./workshops organized								**4**
	# Invited lectures								**31**
	# Awarded grants	6	2	1		4	3	2	**18**
	Awarded grant vol. (k€)	374	627	513		3377	1938	1758	**8586**

F.4.3 Institute for High-Energy Physics

Output

		2011	2012	2013	2014	2015	2016	Total
Publications		217	319	280	226	247	267	1556
Theses		6	8	7	3	12	9	45
ATLAS	Pub	118	173	109	108	135	144	787
	Thes	3	4	1	2	6	4	20
LHCb	Pub	55	92	124	83	80	63	497
	Thes	1	2	2	1	2	2	10
Neutrino Telescopes	Pub	14	10	18	4	6	20	72
	Thes	1	1	1			1	4
Gravitational Waves	Pub	14	33	12	23	14	27	123
	Thes	1		2		1	2	6
Dark Matter	Pub		3	4	3	3	5	18
	Thes					1		1
Detector R&D	Pub	16	8	13	5	9	8	59
	Thes		1		1	2		4

Five most cited papers (excluding self-citations) in the SPIRES/INSPIRE database (May 2017).

Article	Citations
Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ATLAS Collaboration, Phys. Lett. B716 (2012) 1	6300
Dark Matter Results from 225 Live Days of XENON100 Data XENON100 Collaboration, Phys. Rev. Lett. 109 (2012) 181301	1259
Observation of Gravitational Waves from a Binary Black Hole Merger LIGO Scientific and VIRGO Collaborations, Phys. Rev. Lett. 116 (2016) 061102	1192
Combined search for the Standard Model Higgs boson using up to 4.9 fb^{-1} of pp collision data at $\sqrt{s}=7$ TeV with the ATLAS detector at the LHC ATLAS Collaboration, Phys. Lett. B710(2012)49	578
Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence LIGO Scientific and VIRGO Collaborations, Phys. Rev. Lett. 116 (2016) 241103	556

F.4.4 Institute for Theoretical Physics

Year	2010	2011	2012	2013	2014	2015	2016
# Invited talks at workshop and conferences	29	34	39	48	66	79	88
# Invited seminars and colloquia	26	47	38	41	67	75	63
# Lecture series at schools	1	5	5	6	12	17	14
# Schools, work-shops and confer-ences organized	10	11	9	15	11	20	21
# PhD's awarded	5	1	3	6	4	5	6
# Editorships	3	7	10	11	11	11	14
# Talks/courses for high-school students / teachers	4	9	10	13	12	14	12
# Talks for a general audience	7	14	12	28	25	34	35

F.5 Citation analysis

The following tables were taken from the Bibliometric Analysis prepared by the joint University Libraries of UvA and VU, which is provided as a separate document. It contains the number of publications (*N*), the number of citations (*C*), the corresponding world average of citations (W_{avg}), the citations per publication (*CPP*), the relative impact (*RI*) as well as the number and fraction of publications in the top 10% (*T*10) and top 1% (*T*1) of highest cited publications, respectively.
Further details can be found in the full Bibliometric Analysis report, linked through Appendix F.10.1.

F.5.1 LaserLaB

Year	N	C	Wavg	CPP	RI	T10	T10perc	T1	T1perc
2010	128	4959	2342	39	2,22	39	30%	5	4%
2011	152	4077	2365	27	1,80	35	23%	2	1%
2012	182	4583	2274	25	2,19	59	32%	6	3%
2013	150	3099	1521	21	1,97	34	23%	4	3%
2014	179	2654	1272	15	2,13	51	28%	7	4%
2015	161	958	652	6	1,59	31	19%	2	1%
2016	141	372	143	3	2,65	49	35%	5	4%

F.5.2 Van der Waals-Zeeman Institute

Year	N	C	Wavg	CPP	RI	T10	T10perc	T1	T1perc
2010	45	1486	661	33	2,23	14	31%	1	2%
2011	29	642	377	22	1,68	7	24%	0	0%
2012	30	758	340	25	2,25	8	27%	3	10%
2013	38	716	333	19	2,16	12	32%	1	3%
2014	33	713	211	22	3,20	10	30%	2	6%
2015	49	375	181	8	2,11	11	22%	1	2%
2016	78	303	78	4	4,08	25	32%	6	8%

F.5.3 Institute for High-Energy Physics

Year	N	C	Wavg	CPP	RI	T10	T10perc	T1	T1perc
2010	130	6231	2056	48	3,15	45	35%	6	5%
2011	186	5670	2501	30	2,33	64	34%	10	5%
2012	278	13523	3234	49	4,32	118	42%	17	6%
2013	245	7701	2242	31	3,57	100	41%	23	9%
2014	203	4098	1361	20	3,09	89	44%	15	7%
2015	253	3898	948	15	4,21	111	44%	27	11%
2016	310	4146	310	13	13,49	167	54%	54	17%

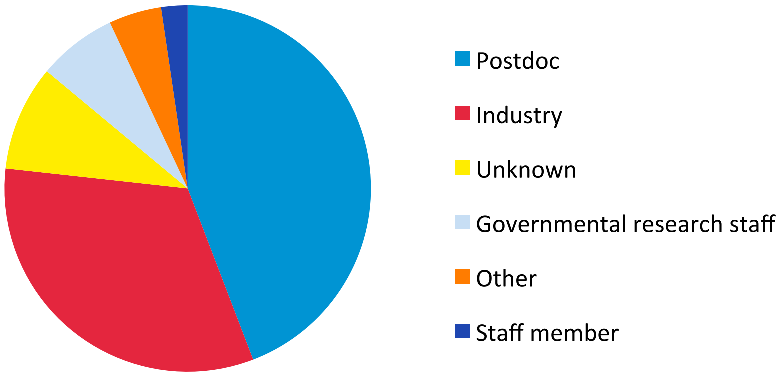
F.5.4 Institute for Theoretical Physics

Year	N	C	Wavg	CPP	RI	T10	T10perc	T1	T1perc
2010	60	1311	902	22	1,48	13	22%	0	0%
2011	55	1989	754	36	2,64	18	33%	4	7%
2012	56	1604	652	29	2,52	20	36%	5	9%
2013	65	1736	606	27	2,96	23	35%	3	5%
2014	65	1472	475	23	3,24	33	51%	4	6%
2015	96	1388	387	14	3,67	43	45%	9	9%
2016	113	708	121	6	5,95	62	55%	15	13%

F.6 Length and success rate of PhD trajectories, exit numbers

F.6.1 LaserLaB

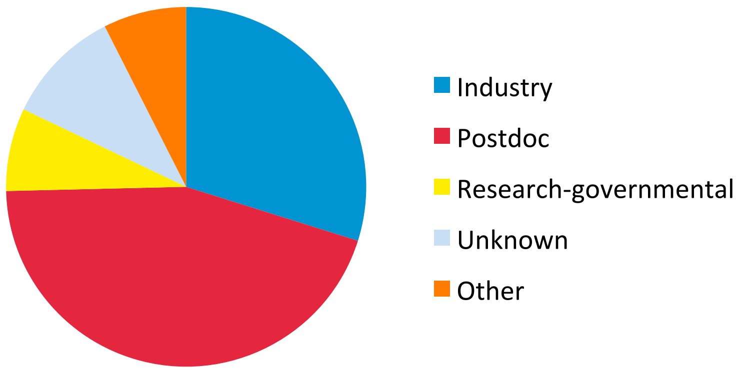
Enrolment				Success Rates					
Starting year	Enrolment (male/female)			<= 48 months	<=60 months	<=72 months	<=84 months	Not yet finished	Discontinued
	M	F	Total	#	#	#	#	#	#
T-10 (2006)	6	0	6	1 (17%)	3 (50%)	6 (100%)	6 (100%)	0 (0%)	0 (0%)
T-9 (2007)	7	0	7	2 (29%)	5 (71%)	5 (71%)	5 (71%)	0 (0%)	2 (29%)
T-8 (2008)	6	0	6	1 (17%)	3 (50%)	4 (67%)	6 (100%)	0 (0%)	0 (0%)
T-7 (2009)	15	2	17	3 (18%)	10 (59%)	13 (76%)	13 (76%)	0 (0%)	3 (18%)
T-6 (2010)	5	3	8	0 (0%)	2 (25%)	2 (25%)	6 (75%)	1 (13%)	1 (13%)
T-5 (2011)	13	6	19	1 (5%)	7 (37%)	9 (47%)	9 (47%)	9 (47%)	1 (5%)
T-4 (2012)	9	0	9	2 (18%)	4 (36%)	5 (45%)	5 (45%)	6 (55%)	0 (0%)
2006-2012	**61**	**11**	**72**	**10 (14%)**	**34 (46%)**	**44 (59%)**	**50 (68%)**	**16 (22%)**	**7 (9%)**



Sectors in which LaserLaB alumni obtained their first job after obtaining their PhD degree.

F.6.2 Van der Waals-Zeeman Institute

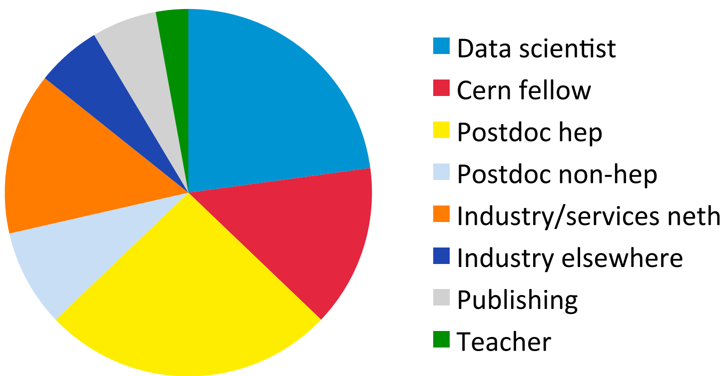
Enrolment				Success Rates					
Starting year	Enrolment (male/female)			<= 48 months	<=60 months	<=72 months	<=84 months	Not yet finished	Discontinued
	M	F	Total	#	#	#	#	#	#
T-10 (2006)	4	1	5	0 (0%)	2 (40%)	3 (60%)	4 (80%)	0 (0%)	1 (20%)
T-9 (2007)	4	1	5	1 (20%)	3 (60%)	3 (60%)	3 (60%)	1 (20%)	1 (20%)
T-8 (2008)	2	3	5	2 (40%)	4 (80%)	5 (100%)	5 (100%)	0 (0%)	0 (0%)
T-7 (2009)	6	2	8	4 (50%)	7 (88%)	8 (100%)	8 (100%)	0 (0%)	0 (0%)
T-6 (2010)	6	2	8	3 (38%)	5 (63%)	6 (75%)	6 (75%)	1 (13%)	1 (13%)
T-5 (2011)	5	0	5	1 (20%)	5 (100%)	5 (100%)	5 (100%)	0 (0%)	0 (0%)
T-4 (2012)	9	3	12	0 (0%)	6 (50%)	6 (50%)	6 (50%)	5 (42%)	1 (8%)
2006-2012	**36**	**12**	**48**	**11 (23%)**	**32 (67%)**	**36 (75%)**	**37 (77%)**	**7 (15%)**	**4 (8%)**



Sectors in which WZI alumni obtain their first job after obtaining their PhD degree (based on 67 PhDs).

F.6.3 Institute for High-Energy Physics

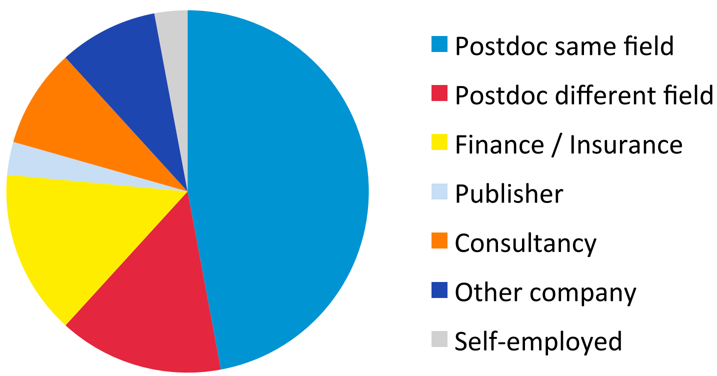
Enrolment				Success Rates				
Starting year	Enrolment (male/female)			<= 48 months	<=60 months	<=72 months	Not yet finished	Discontinued
	M	F	Total	#	#	#	#	#
T-10 (2006)	5	2	7	1 (14%)	5 (71%)	7 (100%)	0 (0%)	0 (0%)
T-9 (2007)	5	1	6	0 (0%)	6 (100%)	6 (100%)	0 (0%)	0 (0%)
T-8 (2008)	6	4	10	0 (0%)	6 (60%)	8 (80%)	0 (0%)	0 (0%)
T-7 (2009)	6	3	9	0 (0%)	5 (56%)	8 (89%)	0 (0%)	0 (0%)
T-6 (2010)	2	3	5	1 (20%)	3 (60%)	5 (100%)	0 (0%)	0 (0%)
T-5 (2011)	12	1	13	1 (8%)	10 (77%)	12 (92%)	0 (0%)	1 (8%)
T-4 (2012)	8	2	10	3 (30%)	6 (60%)	-	3 (30%)	1 (10%)
2006-2012	**44**	**16**	**60**	**6 (10%)**	**41 (68%)**	**46 (77%)**	**3 (5%)**	**2 (3%)**



Sectors in which Nikhef alumni obtain their first job after obtaining their PhD degree. The figure is based on data from OSAF about 35 PhD students of Nikhef (i.e., not exclusively IHEF) who graduated in 2014 and 2015.

F.6.4 Institute for Theoretical Physics

Enrolment				Success Rates					
Starting year	Enrolment (male/female)			<= 48 months	<=60 months	<=72 months	<=84 months	Not yet finished	Discontinued
	M	F	Total	#	#	#	#	#	#
T-10 (2006)	2	1	3	2 (67%)	2 (67%)	2 (67%)	2 (67%)	0 (0%)	1 (33%)
T-9 (2007)	2	0	2	0 (0%)	1 (50%)	2 (100%)	2 (100%)	0 (0%)	0 (0%)
T-8 (2008)	2	2	4	2 (50%)	2 (50%)	4 (100%)	4 (100%)	0 (0%)	0 (0%)
T-7 (2009)	4	1	5	4 (80%)	5 (100%)	5 (100%)	5 (100%)	0 (0%)	0 (0%)
T-6 (2010)	3	0	3	1 (33%)	3 (100%)	3 (100%)	3 (100%)	0 (0%)	0 (0%)
T-5 (2011)	5	3	8	4 (50%)	6 (75%)	7 (88%)	7 (88%)	0 (0%)	1 (13%)
T-4 (2012)	6	1	7	2 (29%)	4 (57%)	4 (57%)	4 (57%)	2 (29%)	1 (14%)
2006-2012	**24**	**8**	**32**	**15 (47%)**	**23 (72%)**	**27 (84%)**	**27 (84%)**	**2 (6%)**	**3 (9%)**



Sectors in which ITFA alumni obtain their first job after obtaining their PhD degree, based on a total of 34 PhDs.

F.7 Key scientific publications

F.7.1 LaserLaB

- *A Stringent Limit on a Drifting Proton-to-Electron Mass Ratio from Alcohol in the Early Universe*. Bagdonaite, J., P. Jansen, C. Henkel, H.L. Bethlem, K.M. Menten, and W. Ubachs. **Science**. 339:46-48 (2013).
- *Minimally Invasive Micro-Indentation: mapping tissue mechanics at the tip of an 18G needle.* Beekmans, S.V., K.S. Emanuel, T.H. Smit, and D. Iannuzzi. **Sci Rep-Uk.** 7 (2017).
- *Fiber-based polarization-sensitive OCT of the human retina with correction of system polarization distortions.* Braaf, B., K.A. Vermeer, M. de Groot, K.V. Vienola, and J.F. de Boer. **Biomed Opt Express.** 5:2736-2758 (2014).
- *Angiography of the retina and the choroid with phase-resolved OCT using interval-optimized backstitched B-scans. Braaf, B., K.A. Vermeer, K.V. Vienola, and J.F. de Boer.* **Opt Express**. 20:20516-20534 (2012).
- *Resolving coiled shapes reveals new reorientation behaviors in C-elegans*. Broekmans, O.D., J.B. Rodgers, W.S. Ryu, and G.J. Stephens. **Elife**. 5 (2016).
- *Sliding sleeves of XRCC4-XLF bridge DNA and connect fragments of broken DNA*. Brouwer, I., G. Sitters, A. Candelli, S.J. Heerema, I. Heller, A.J. de Melo, H.S. Zhang, D. Normanno, M. Modesti, E.J.G. Peterman, and G.J.L. Wuite. **Nature**. 535:566-+ (2016).
- *Molecular Fountain*. Cheng, C., A.P.P. van der Poel, P. Jansen, M. Quintero-Perez, T.E. Wall, W. Ubachs, and H.L. Bethlem. **Phys Rev Lett.** 117 (2016).
- *LHCSR1 induces a fast and reversible pH-dependent fluorescence quenching in LHCII in Chlamydomonas reinhardtii cells*. Dinc, E., L.J. Tian, L.M. Roy, R. Roth, U. Goodenough, and R. Croce. **P Natl Acad Sci USA**. 113:7673-7678 (2016).
- *Plasmon-Enhanced Photocurrent of Photosynthetic Pigment Proteins on Nanoporous Silver.* Friebe, V.M., J.D. Delgado, D.J.K. Swainsbury, J.M. Gruber, A. Chanaewa, R. van Grondelle, E. von Hauff, D. Millo, M.R. Jones, and R.N. Frese. **Adv Funct Mater**. 26:285-292 (2016).
- *STED nanoscopy combined with optical tweezers reveals protein dynamics on densely covered DNA*. Heller, I., G. Sitters, O.D. Broekmans, G. Farge, C. Menges, W. Wende, S.W. Hell, E.J.G. Peterman, and G.J.L. Wuite. **Nat Methods.** 10:910-U132 (2013).
- *Extreme Ultraviolet Frequency Comb Metrology*. Kandula, D.Z., C. Gohle, T.J. Pinkert, W. Ubachs, and K.S.E. Eikema. **Phys Rev Lett**. 105 (2010).
- *Third harmonic generation imaging for fast, label-free pathology of human brain tumors.* Kuzmin, N.V., P. Wesseling, P.C.D. Hamer, D.P. Noske, G.D. Galgano, H.D. Mansvelder, J.C. Baayen, and M.L. Groot. **Biomed Opt Express**. 7:1889-1904 (2016).
- *Regulation of Light Harvesting in the Green Alga Chlamydomonas reinhardtii: The C-Terminus of LHCSR Is the Knob of a Dimmer Switch*. Liguori, N., L.M. Roy, M. Opacic, G. Durand, and R. Croce. **J Am Chem Soc**. 135:18339-18342 (2013).
- *Proton-Coupled Electron Transfer Constitutes the Photoactivation Mechanism of the Plant Photoreceptor UVR8*. Mathes, T., M. Heilmann, A. Pandit, J.Y. Zhu, J. Ravensbergen, M. Kloz, Y.A. Fu, B.O. Smith, J.M. Christie, G.I. Jenkins, and J.T.M. Kennis. **J Am Chem Soc.** 137:8113-8120 (2015).
- *$NaTaO_3$ Photoanode for Bias-Free Water Splitting: A Photo-Electrochemical and Kelvin Probe Surface Photovoltage Study*. Polak, L., J.H. Rector, M.J. Slaman, and R.J. Wijngaarden. **J Phys Chem C**. 120:23559-23565 (2016).
- *Quantum coherence in photosynthesis for efficient solar-energy conversion*. Romero, E., R. Augulis, V.I. Novoderezhkin, M. Ferretti, J. Thieme, D. Zigmantas, and R. van Grondelle. **Nat Phys**. 10:677-683 (2014).
- *Strain-controlled criticality governs the nonlinear mechanics of fibre networks.* Sharma, A., A.J. Licup, K.A. Jansen, R. Rens, M. Sheinman, G.H. Koenderink, and F.C. MacKintosh. **Nat Phys**. 12:584-+ (2016).
- *Frequency Metrology in Quantum Degenerate Helium: Direct Measurement of the 2 S-3(1) -> 2 S-1(0) Transition*. van Rooij, R., J.S. Borbely, J. Simonet, M.D. Hoogerland, K.S.E. Eikema, R.A. Rozendaal, and W. Vassen. **Science**. 333:196-

198 (2011).

- *Interplay between Long-Range Crystal Order and Short-Range Molecular Interactions Tunes Carrier Mobility in Liquid Crystal Dyes*. Yimga, N.T., C. Ramanan, H. Borchert, J. Parisi, H. Untenecker, P. Kirsch, and E. von Hauff. **ACS Appl Mater Inter**. 9:6228-6236 (2017).

F.7.2 Van der Waals-Zeeman Institute

Hard condensed matter

- *Carrier multiplication in Ge nanocrystals.* S. Saeed, C. de Weerd, P. Stallinga, F.C.M. Spoor, A. J. Houtepen, L.D.A. Siebbeles, and T. Gregorkiewicz. **Light: Science & Applications** 4, e251:1-6 (2015); doi: 10.1038/lsa.2015.24.
- *Red spectral shift and enhanced quantum efficiency in phonon-free photoluminescence from silicon nanocrystals.* W.D.A.M. de Boer, D. Timmerman, K. Dohnalová, I.N. Yassievich, H. Zhang, W.J. Buma, and T. Gregorkiewicz. **Nature Nanotechnology** 5, 878-884 (2010).
- *Kondo hybridisation and the origin of metallic states at the (001) surface of SmB_6.* E. Frantzeskakis, N. de Jong, B. Zwartsenberg, Y. K. Huang, Y. Pan, X. Zhang, J. X. Zhang, F. X. Zhang, L. H. Bao, O. Tegus, A. Varykhalov, A. de Visser, M. S. Golden. **Phys. Rev. X** 3, 041024 (2013).
- *Superconductivity in the doped topological insulator $Cu_xBi_2Se_3$ under high pressure*. T.V. Bay, T. Naka, Y.K. Huang, H. Luigjes, M.S. Golden and A. de Visser. **Phys. Rev. Lett.** 108 (2012) 057001-1:4.
- *Speed limit of the insulator–metal transition in magnetite.* S. de Jong, R. Kukreja, C. Trabant, N. Pontius, C. F. Chang, T. Kachel, M. Beye, F. Sorgenfrei, C. H. Back, B. Bräuer,W. F. Schlotter, J. J. Turner, O. Krupin, M. Doehler, D. Zhu, M. A. Hossain, A. O. Scherz, D. Fausti, F. Novelli, M. Esposito, W. S. Lee, Y. D. Chuang, D. H. Lu, R. G. Moore, M. Yi, M. Trigo, P. Kirchmann, L. Pathey, M. S. Golden, M. Buchholz, P. Metcalf, F. Parmigiani,W.Wurth, A. Föhlisch, C. Schüßler-Langeheine and H. A. Dürr. **Nature Materials,12**, 882-886 (2013)
- *Superconductivity in the doped topological insulator $Cu_xBi_2Se_3$ under high pressure. T.V. Bay, T. Naka, Y.K. Huang, H. Luigjes, M.S. Golden and A. de Visser.* **Phys. Rev. Lett.** 108 (2012) 057001-1:4.

Soft Matter

- *Sliding friction on wet and dry sand*. A Fall, B Weber, M Pakpour, N Lenoir, N Shahidzadeh, J Fiscina, D. Bonn. **Phys. Rev. Lett.** 112 (17), 175502 (2014).
- *Metastability limit for the nucleation of NaCl crystals in confinement*. J Desarnaud, H Derluyn, J Carmeliet, D Bonn, N Shahidzadeh. **J. Phys. Chem. Letters** 5 (5), 890-895 (2014).
- *Controlling colloidal phase transitions with critical Casimir forces.* Nguyen, VD Faber, S Hu, ZB Wegdam, GH Schall, P. **Nature Communications** 4, 1584 (2013).
- *Zeta potential in porous rocks in contact with monovalent and divalent electrolyte aqueous solutions*. Luong Duy Thanh and Rudolf Sprik. Geophysics, 81(4), D303-D314 (2016).
- *Long-range strain correlations in sheared colloidal glasses*. V Chikkadi, G Wegdam, D Bonn, B Nienhuis, P Schall. **Phys. Rev. Lett.** 107 (19), 198303 (2011).

Quantum Gases and Quantum Information

- *Sub-Poissonian atom number fluctuations by three-body loss in mesoscopic ensembles.* S. Whitlock, C. F. Ockeloen, and R. J. C. Spreeuw, **Phys. Rev. Lett.** 104, 120402 (2010).
- *Spatially resolved excitation of Rydberg atoms and surface effects on an atom chip*. Atreju Tauschinsky, Rutger M. T. Thijssen, S. Whitlock, H. B. van Linden van den Heuvell, and R. J. C. Spreeuw. **Phys. Rev. A** 81, 063411 (2010).
- *Yang-Yang thermometry and momentum distribution of a trapped one-dimensional Bose gas*. M.J. Davis, P.B. Blakie, A.H. van Amerongen, N.J. van Druten, and K.V. Kheruntsyan. **Phys. Rev. A** 85: 031604(R) (2012).

- *Raman transitions between hyperfine clock states in a magnetic trap*. J. B. Naber, L. Torralbo-Campo, T. Hubert, and R. J. C. Spreeuw. **Phys. Rev. A** 94, 013427 (2016).
- *Controlled long-range interactions between Rydberg atoms and ions*. T. Secker, R. Gerritsma, A. W. Glaetzle, and A. Negretti. **Phys. Rev. A** 94, 013420 (2016).

F.7.3 Institute for High-Energy Physics

- *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC.* ATLAS Collaboration, **Phys. Lett. B**716 (2012) 1.
- *Dark Matter Results from 225 Live Days of XENON100 Data.* XENON100 Collaboration, **Phys. Rev. Lett.** 109 (2012) 181301.
- *Observation of Gravitational Waves from a Binary Black Hole Merger.* LIGO Scientific and VIRGO Coll., **Phys. Rev. Lett.** 116 (2016) 061102.
- *Combined search for the Standard Model Higgs boson using up to 4.9 fb^{-1} of pp collision data at $\sqrt{s}$=7 TeV with the ATLAS detector at the LHC.* ATLAS Collaboration, **Phys. Lett. B**710(2012)49.
- *Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence.* LIGO Scientific and VIRGO Coll., **Phys. Rev. Lett.** 116 (2016) 241103.
- *QCD evolution of (un)polarized gluon TMDPDFs and the Higgs q_T distribution*, M. G. Echevarria et al. (P. Mulders), **JHEP** 1507 (2015) 158.
- *Transverse Momentum Dependent (TMD) Parton Distribution Functions: Status and Prospects*, R. Angeles Martinez et al. (P. Mulders), **Acta Phys. Polon.** B46 (2015) 2501.
- *Probing new physics via the $B_s^0 \rightarrow \mu\mu$ effective lifetime*, K. de Bruyn et al. (R. Fleischer), **Phys. Rev. Lett.** 109 (2012) 041801.
- *Implications of LHCb measurements and future prospects*, LHCb Collaboration (M. Merk, G. Raven, R. Fleischer), **Eur. Phys. J.** C73 (2013) 2373.
- *Observation of the rare $B_s^0 \rightarrow \mu\mu$ decay from the combined analysis of CMS and LHCb data*, LHCb and CMS Collaborations (M. Merk, G. Raven), **Nature** 522 (2015) 68.
- *Searches for point-like and extended neutrino sources close to the Galactic Centre using the Antares neutrino telescope*, Antares Collaboration (R. Bruijn, P. Kooijman, E. de Wolf), **Astrophys. J.** 786 (2014) L5.
- *Letter of Intent for KM3NeT 2.0, KM3NeT Collaboration (R. Bruijn, P. Kooijman, E. de Wolf),* **J. Phys. G**43 (2016) 084001.

F.7.4 Institute for Theoretical Physics

Rather than providing a list of ten important publications we have chosen to include a slightly longer list of papers with a brief description for each below. The list includes two publications for each staff member present at ITFA throughout the entire evaluation period, and one publication for those who joined later. In view of the limited space for scientific content in this self-evaluation, the list below is aimed at conveying both the breadth and depth of ITFA research, and is in our opinion more instructive than a plain list of publications without context.

- *Understanding quantum measurement from the solution of dynamical models,* A.E. Allahverdyan, R. Balian, **T.M. Nieuwenhuizen**, Physics Reports 525, 1-166 2013.

  After a comprehensive review of models for quantum measurement, the dynamics is worked out for the Curie-Weiss model. Three successive mechanisms occur: truncation of the density matrix ("collapse of the wave function"); registration of the outcome; and sub-ensemble relaxation, a new mechanism, which allows to connect to the quantum measurement problem.
- *Charge Order from Orbital-dependent Coupling Evidenced by NbSe2,* Felix Flicker and **Jasper van Wezel**, Nature Commun., 6, 7034 (2015).

Provides the definitive theory (with experimental support) for the mechanism leading to charge order in the prototypical CDW material NbSe2. Especially the detailed role played by the momentum and orbital dependence of electron-phonon coupling is found to be an omnipresent and universally important ingredient in all CDW materials.

- *Fractional spinon excitations in the quantum Heisenberg antiferromagnetic chain,* M. Mourigal, M. Enderle, A. Klöpperpieper, **J.-S. Caux**, A. Stunault, H. M. Rønnow, Nature Physics 9, 435-441 (2013).

  Dynamical correlation functions of integrable spin chains and atomic gases were computed from integrability, and matched to inelastic neutron scattering.

- *Time evolution of local observables after quenching to an integrable model,* **J.-S. Caux** and F. H. L. Essler, Phys. Rev. Lett. 110, 257203 (2013).

  A method known as the Quench Action was developed, allowing to obtain the first exact analytical descriptions of quantum quenches in one-dimensional systems.

- *Strange metals in one spatial dimension,* R. Gopakumar, A. Hashimoto, I.R. Klebanov, S. Sachdev and **K. Schoutens**, Phys. Rev. D86 (2012) 066003.

  We consider D=1+1 SU(N) gauge theory coupled to a massive Dirac fermions in the adjoint representation. The high-density limit is captured by coset CFT with an emergent N = (2, 2) supersymmetry. We also compute the low-lying bound states in the low-density limit.

- *Particles in non-Abelian gauge potentials: Landau problem and insertion of non-Abelian flux,* **B. Estienne, S. Haaker and K. Schoutens**, New J Phys. 13, 045012 (2011).

  Emulating non-Abelian gauge potentials is becoming feasible in cold-atom systems. This paper explores the response to such potentials, stressing analogies and differences with the Abelian case.

- *Competing states in the t-J model: uniform d-wave state versus stripe state,* **P. Corboz**, T. M. Rice, and M. Troyer, Phys. Rev. Lett. 113, 046402 (2014).

  State-of-the-art tensor network simulations of the *t-J* model - an effective model of the Hubbard model - reveal an extremely close competition between a uniform d-wave superconducting state and different stripe states, which can also be found in high-Tc superconductors.

- *Statistics and Properties of Low-Frequency Vibrational Modes in Structural Glasses,* **E. Lerner**, G. Düring, and E. Bouchbinder, Phys. Rev. Lett. 117, 035501 (2016).

  It was found that the low-frequency spectra of disordered solids follow a universal form, independent of spatial dimension or microscopic details.

- *Detecting Berry curvature in the dynamical Hall effect,* **V. Gritsev**, A. Polkovnikov, PNAS 109, 6457 (2012).

  These theoretical proposals, based on quantum geometric theory for non-equilibrium dynamics, have been implemented by several experimental groups, including Martini's group at Google, and Spielman's group at the Quantum Institute in Maryland.

- *Direct Measurement of the Free Energy of Aging Hard Sphere Colloidal Glasses,* R. Zargar, **B. Nienhuis**, P. Schall, D. Bonn, Phys. Rev. Lett. 110, 258301 (2013).

  Ordinarily the free energy is not a measurable quantity. In this article we nevertheless report a direct measurement. It gives us access to the so-called free-energy landscape, which plays an important role in understanding glasses, but until now remained abstract.

- *Parity Effects in the Scaling of Block Entanglement in Gapless Spin Chains,* P. Calabrese, M. Campostrini, F. Essler, **B. Nienhuis**, Phys. Rev. Lett. 104, 095701 (2010).

  This article shows the effectiveness of using the entanglement spectrum to measure accurately critical exponents and scaling functions.

- *Employing Helicity Amplitudes for Resummation*, I. Moult, I. W. Stewart, F. J. Tackmann, **W. J. Waalewijn,** Phys. Rev. D 93, 094003 (2016) *editor's selection*

  We construct a helicity operator basis in Soft-Collinear Effective Theory that makes it straightforward to combine state-of-the-art fixed-order calculations with resummation.

- *Coherent Cascade Conjecture for Collapsing Solutions in Global AdS,* **Ben Freivogel**, I-Sheng Yang, Phys.Rev. D93 (2016) no.10, 103007

  We derived a simple analytical expression for the energy spectrum in gravitational collapse which agrees with existing numerical results. Our results connect the theory of turbulence to gravitational instabilities of Anti-de Sitter spacetime.

- *Evidence for dark matter in the inner Milky Way,* F. Iocco, M. Pato, **G. Bertone**, Nature Phys. 11 (2015) 245-248

  We show that current data demonstrate the existence of dark matter in the inner regions of the Milky Way.

- *Global Fits of the cMSSM and NUHM including the LHC Higgs discovery and new XENON100 constraints*, C. Strege, **G. Bertone**, F. Feroz, M. Fornasa, R. Ruiz de Austri, R. Trotta, JCAP 1304 (2013) 013

  We assessed the implications of the discovery of the Higgs boson on the most popular extensions of the Standard Model of particle physics.

- *Tomographic Constraints on High-Energy Neutrinos of Hadronuclear Origin*, **S. Ando, I. Tamborra, F. Zandanel**, Physical Review Letters 115, 221101 (2015)

  This paper presents new constraints on neutrino sources using a technique developed in gamma-ray astrophysics and cosmology.

- *Dirac neutrino mass from a neutrino dark matter model for the galaxy cluster Abell* 1689, **T.M. Nieuwenhuizen**, Journal of Physics: Conference Series 701 (1) 2017

  Predicts mass of the neutrino; Dirac signature, so 3 sterile partners; constitute the solution of the dark matter riddle. To be tested in KATRIN 2018.

- *Emergence in Holographic Scenarios for Gravity*, Dennis Dieks, **Jeroen van Dongen**, Sebastian de Haro, Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics (2015) 52, 203-216.

  This article is a key publication in bringing holography to the philosophical literature, with a focus on issues of 'emergence' and epistemological interpretation, for which it makes it makes entirely novel proposals.

- *Derivation of the null energy condition*, Maulik Parikh, **Jan Pieter van der Schaar,** Phys. Rev. D **91**, 084002 (3 April 2015)

  In this paper we derive the null energy condition, understood as a constraint on the Einstein-frame Ricci tensor, as a consequence of worldsheet diffeomorphism invariance in string theory.

- *Squark and gluino hadroproduction,* W. Beenakker, S. Brensing, M. Kramer, A. Kulesza, **E. Laenen**, L. Motyka and I. Niessen, Int. J. Mod. Phys. A 26 (2011) 2637

  We derived the NLL resummed production cross sections for squark and gluino production at the LHC and constructed the corresponding public code NLLFast, now much used by ATLAS and CMS.

- *Imaginary parts and discontinuities of Wilson line correlators*, **E. Laenen**, K.J Larsen and **R. Rietkerk**, Phys. Rev. Lett. 114 (2015) no.18, 181602

  We derived cutting rules for eikonal diagrams, using coordinate space field theory. The paper featured on the cover of PRL.

- *Umbral Moonshine and Niemeier Lattices,* **M. C. Cheng**, J.F. Duncan, J.A. Harvey, Mathematical Sciences (2014) 1: 3

  The discovery of umbral moonshine, a new type of connection between modular objects and finite simple groups, in the context of supersymmetric string theory.

- *New Target for Cosmic Axion Searches*, **D. Baumann,** D. Green and B. Wallisch, Phys. Rev. Lett. 117, no. 17, 171301 (2016).

  This paper proposes a new way to search for light axions using precise measurements of the CMB anisotropy spectrum. The result has been adopted as one of the main science targets of the future CMB Stage 4 missions.

- *Inflation and String Theory*, **D. Baumann** and L. McAllister, Cambridge University Press (2014).

  This book reviews more than a decade of research in inflation and attempts to connect it to string theory. It has become a standard reference in the field.
- *Strong support for the millisecond pulsar origin of the Galactic center GeV excess*, **R. Bartels, S. Krishnamurthy, C.Weniger**, Phys. Rev. Lett. 116 (2016) 051102

  We found strong observational evidence that the "Galactic center GeV excess" is in fact of astrophysical origin, and not a dark matter annihilation signal.
- *Holographic entanglement entropy and gravitational anomalies*, **A. Castro**, S. Detournay, N. Iqbal and E. Perlmutter, JHEP 1407, 114 (2014)

  We studied entanglement entropy for theories that suffer from a gravitational anomaly. From a field-theoretical point of view, we further understood the interplay between anomalies and entanglement entropy. From a holographic perspective, in gravitational theories with anomalies, entanglement entropy probes not only geodesic distances, but also other aspects of the dual bulk geometry, which we showed explicitly.
- *A proof of the Conformal Collider* Bounds, **D. Hofman**, D. Li, D. Meltzer, D. Poland, **F. Rejon-Barrera**, JHEP 1606 (2016) 111

  This paper provides a rigorous proof of the important bound for central charges of any Conformal Field Theory conjectured in JHEP 0805 (2008)
- *Emergent Gravity and the Dark Universe*, **E. P. Verlinde**, SciPost Phys. 2 (2017) no.3, 016

  The ideas behind the emergence of gravity from quantum entanglement are extended to de Sitter space. We find that the entropy density associated with the positive dark energy leads to modifications of general relativity and explains the phenomena attributed to dark matter.
- *Black Hole Entanglement and Quantum Error Correction*, **E.P. Verlinde,** H. Verlinde, JHEP 1310 (2013) 107

  We address a version of the black hole information paradox, known as the "firewall paradox". It is shown that the entanglement of the microscopic black hole quantum state with the emitted radiation allows one to reconstruct the interior of the black hole.
- *Resurgent Transseries and the Holomorphic Anomaly,* R. Couso-Santamaría, J. D. Edelstein, R. Schiappa, **M. Vonk**, Annales Henri Poincare 17 (2016) no.2, 331-399

  This paper generalized the holomorphic anomaly equation, the central equation for solving topological string theories, to a fully nonperturbative setting
- *Bulk curves from boundary data in* holography, V Balasubramanian, BD Chowdhury, B Czech, **J de Boer**, MP Heller, Physical Review D 89 (8), 086004 (2014)

  This paper explains how to reconstruct the length of a curve in particular types of spacetimes from quantum information theoretic data, which was a significant step forward in understanding the emergence of spacetime.
- *Holographic thermalization*, V Balasubramanian, A Bernamonti, **J de Boer**, N Copland, B Craps, et al, Physical Review D 84 (2), 026010 (2011)

  We study thermalization in a model which closely resembles strongly coupled QCD and find that thermalization proceeds from high to low energies rather than the other way around, which was a surprise. This was one of the first papers discussing these types of out-of-equilibrium processes in AdS/CFT.

F.8 Societal Impact

F.8.1 LaserLaB

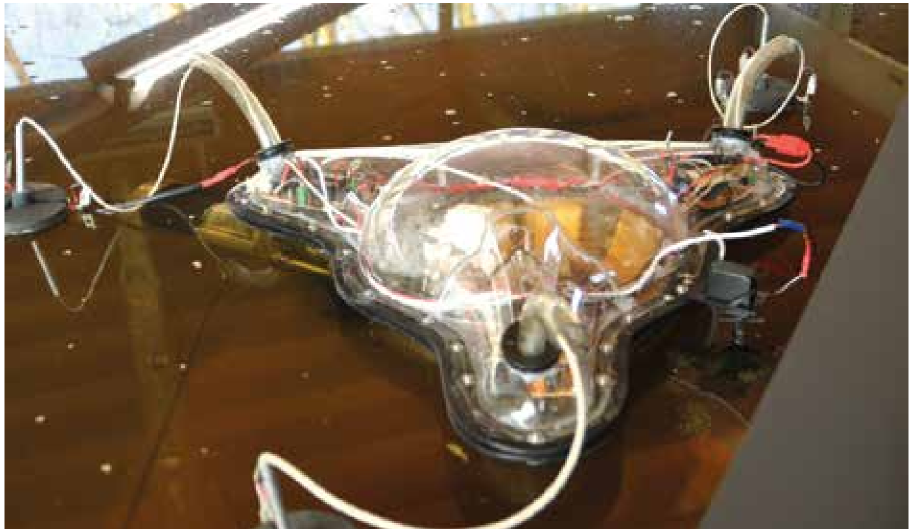
LaserLaB strives to have impact on society as a whole on four different levels.

1. **Addressing big societal question with research.** Research performed in LaserLaB is not only curiosity driven (with the goal to enlarge fundamental knowledge), a major part is also motivated by the big societal questions. In particular:
    - The increasing demand for health and longevity requires a better understanding of the basic processes of **life** in order to improve **health**. Part of LaserLaB research is focused on the development and application of novel optical methods, techniques and instruments to study the interaction between proteins, DNA, cells and tissue. This knowledge will lead to innovative diagnostic and therapeutic techniques.
    - Sustainable **energy** production will play a crucial role in our future. The process of photosynthesis in plants is the process that sustains virtually all life on Earth and is also an excellent example of renewable energy production. By studying this process, it is possible to develop more efficient natural and artificial solar-energy converters for the production of food and fuel.

    This focus on societal questions fits well within the focus of the VU to strengthen the connection between science and society and its particular emphasis on four themes, of which **Human Health & Life Sciences** and **Science for Sustainability** are the ones most relevant for LaserLaB.
2. **Outreach** to get **high-school students** interested in physics and astronomy in general, LaserLaB research, and the educational programmes LaserLaB is involved in. To this end, LaserLaB is involved in information activities, including open house days. In addition, the VU/UvA physics and astronomy physics practicals and didactics staff organize activities for high-school students and high-school teachers.
3. LaserLaB puts large emphasis on the education of young people. We achieve this by our participation in the **Physics and Astronomy** BSc and MSc programmes, in the **Medical Natural Science** BSc and MSc programmes, and the **Science, Business and Innovation** BSc and MSc programmes. In addition, we achieve this by training highly skilled PhD students, who after graduating find jobs in companies, government, education and academia.
4. **Outreach** to the **general audience**. LaserLaB researchers take many opportunities to present their work to the general audience. These can be divided in several categories:
    - Involvement in **open laboratory days**, such as *Weekend van de Wetenschap* (Weekend of Science).
    - **Public lectures.** Examples that are available online:
        - Eikema: www.youtube.com/watch?v=GB2tV29q974
        - Frese: www.youtube.com/watch?v=hG2uD1h5qbc
        - Iannuzzi: vimeo.com/album/3655491/video/67562921
        - Peterman: youtu.be/FuZh0-4s9Rc
    - **Media attention**. It is common practice to issue a press release when an important discovery is published or in case of other events (award of prestigious grants, awards, professorships). Frequently, such press releases are picked up by the national and international press. LaserLaB scientists have regularly appeared in national newspapers and on national radio. For example:
        - Ubachs in *Volkskrant* 24/03/2012
        - van Grondelle on public radio 03/03/2013
        - Peterman on public radio *Hoe?Zo!* 05/07/2013
        - Peterman on *BNR Nieuwsradio* 27/10/2015
        - Bethlem in *Volkskrant* 14/11/2016
    - **Online videos:**

- van Grondelle: www.youtube.com/watch?v=mCN-nPvciXQ
- Groot: www.youtube.com/watch?v=4bMrQ25Up8s
- Iannuzzi: www.youtube.com/watch?v=4Thmqi0wscw
- Peterman: vimeo.com/70901354
- Wuite: vimeo.com/fastfacts/gijs-wuite-breekbare-virussen
- Wuite: vimeo.com/26477617

- **Exchanges with artists**. Examples are**:**
  - LaserLaB researcher Raoul Frese has, together with artist Ivan Henriques, built an Algae Powered Robot (APR), a floating robot that autonomously searches for photosynthetic material in the form of algae. The algae or small plants are being processed by the robot and utilized as photoactive material for its solar panels. The robot has been on public display and has received substantial media attention with the Netherlands and abroad. See: www.raoulfrese.nl/the-symbiotic-machine/ and vimeo.com/94640442 .



  - Erwin Peterman has given a public lecture together with the Acanthus string quartet, who reacted, with music, on the single-molecule movies presented in the lecture. See: www.vu.nl/nl/nieuws-agenda/nieuws/2014/apr-jun/hectiek-op-de-nanometer.aspx

5. LaserLaB puts emphasis on valorisation of its scientific results via two approaches:
   - LaserLaB is involved in the **Amsterdam Physics Research and Innovation Lab** (APRIL), of which LaserLaB professor Davide Iannuzzi is scientific director. APRIL is an initiative of the collaborating higher education and research institutions in Amsterdam and the city of Amsterdam. APRIL provides entrepreneurs and industry the opportunity to carry out a conceptual or technical feasibility study, conduct short-term studies, or establish more long term collaborations with the Amsterdam research laboratories. One aspect of APRIL is the **Demonstrator Lab**, a facility for students and researchers where bright ideas are transformed into tangible customer added value. The

Demonstrator Lab is located in the same building as LaserLaB.

- LaserLaB researchers have, over the past years, been involved in founding several spin-off companies: Optics11 (Iannuzzi), LUMICKS (Peterman & Wuite), OPNT (Koelemeij) and Triton Diagnostics (Groot). These companies have been described in more detail in Section .

F.8.2 Van der Waals-Zeeman Institute

- The WZI strives to combine fundamental research with potential for technological innovation. Especially the Soft Matter group has a large amount of industrial collaborations, for example with Michelin (rolling resistance of car tires), SKF (friction in ball-bearings) Unilever (fragmentation of bouillon cubes, mouthfeel of food products), Shell (seismics, emulsion rheology and stability), DSM (friction of plastics), Akzo Nobel (salt crystallization), ASML (friction). Bonn is involved in a successful startup company (see www.squall.pro) based on a new and revolutionary kind of additive to prevent pesticide pollution. This breakthrough drew large attention in the media with almost all leading newspapers throughout the world. The innovation is now a product that is being successfully sold in several European countries, and recently acquired almost 1M€ of funding from a 'green' venture capital firm in which the World Wildlife Fund (WWF) is a participant.
- The Hard Condensed Matter group's research on semiconductor nanocrystals aims to tune and manipulates the optical and optoelectronic properties for potential use in (nano)photovoltaics, lighting applications and medicine. This led to many industrial collaborations around the Dutch Joint Solar Programme and in addition has led to Katerina Newell-Dohnalová to co-found the start-up company Spectris-dot B.V. of which she is CSO.
- The paper of the Soft Matter group on friction in relation to the building of the pyramids (Phys. Rev. Lett. 2014) resolved a problem that had been around for hundreds of years: how the Egyptians managed to transport the immense rocks necessary for large constructions. Within days after publication, it went viral on the internet, attracting over a million 'likes' on many of the Facebook pages about this research, in addition to being mentioned in hundreds of journals, websites etc. The research was also picked up by several TV and radio stations, and the BBC and France Televisions devoted quite a lot of attention to it. Similarly, the research of the same group on the maximum height of sandcastles (Scientific Reports 2012) was features in the NY Times, the Times, LA Times, and almost all Dutch journals. Over the evaluation period, a number of TV and radio items were made by among others Dutch, Canadian, US, French and Spanish channels featuring the research on quicksand, sandcastles and the Egyptian pyramids.
- On a more local level, the whole institute contributed to various outreach activities; the most visible of these are the collaborations with Dutch or Amsterdam radio and TV stations and the Science Museum NEMO (several 'kinderlezingen', (science lectures for children), Nemo Klokhuisdag etc.). Mark Golden is one of the main lecturers at the 'Universiteit van Nederland', with a Youtube channel of about a 100,000 views. The new BSc course 'Fluids and Soft Matter' also has its own YouTube channel where BSc students upload their educational videos on a subject related to the course.
- Many of the staff were also involved in the FNWI College Tour, which consists of public lectures as part of the cultural series SPUI25. There were also many other invited outreach lectures: Diligentia, Universiteit Gent, Gala van de Wetenschap etc. A special mention is reserved also for all the activities aimed at inspiring high-school students and their science teachers, with several projects: Back to University, Nemo teacher lectures, receiving high-school teachers for research projects and touring various high schools in the Amsterdam region to inspire both pupils and teachers.

F.8.3 Institute for High-Energy Physics

Media Coverage

The interest of the general public in the research performed by IHEF has been large, as reflected by the creation of a dedicated "route" on the National Science Agenda, "Building blocks of matter and foundations of space and time". In the review period, e.g. the startup of the LHC, the discovery of the Higgs boson and gravitational waves have generated significant media attentions, and offered clear opportunities for outreach. At the level of national media these include interviews in e.g. "De Wereld Draait Door", and national newspapers, lectures at "University of the Netherlands" and "LowLands University". To give an indication of the amount of coverage, the number of articles in print media on IHEF related research and topics reached several hundred in 2012 and 2016, corresponding to the discoveries of the Higgs boson and gravitational waves respectively.

Activities for the media

Contact with the media is coordinated through Nikhef, which publishes on average ten full press releases per year, sent out to an extensive list of Dutch journalists, and distributed through social media. Visits of journalists to CERN, Virgo and Xenon were organised, including ample time for one-on-one interviews.

Outreach talks and activities

In total, some 280 outreach talks have been given by IHEF staff members. These include talks at high schools, science cafes and symposia, science associations and museums. As part of the annual "Weekend Of Science" IHEF members partake in the "Nikhef open dag", which welcomes hundreds of people and features short lectures, demonstrations and tours. Children can partake in special workshop and a particle treasure hunt. The CERN exhibition "LHC Time Tunnel" was brought to the NEMO science museum, and for a few weeks, visitors of NEMO were interactively taken into the world of subatomic physics by using motion sensors and projectors, which allowed visitors to simulate the effect of the Higgs field.

IHEF staff members have featured as interviewees in theatre performances of Jan van den Berg, and the documentary "Higgs into the heart of imagination" of Jan van den Berg and Hannie van den Berg which follows the Dutch Atlas team during the preparations for the start of the LHC was extended to cover the Higgs discovery.

Education

Annually, one-day master classes for high school pupils are organized in collaboration with IPPOG (International Particle Physics Outreach Group), where students learn how collisions in the LHC create new particles, and how to analyse actual LHC data. In total 330 students participated between 2011 and 2016. An additional 124 students were helped to carry out their 'profielwerkstuk' (dedicated science project in their final secondary school year), and 1300 students visited Nikhef for an afternoon program consisting of a lecture, film and guided tour. IHEF staff participates in the annual national "Techniek Toernooi", a science tournament for primary school children, and have presented lectures in the popular "Wakker Worden Kinderlezingen" for children between 8 and 12 years at the NEMO science museum.

Contract Research and collaboration with industry

As part of the gravitational wave research, a collaboration with Shell was initiated around the development of ultralow-power seismic sensors, This has resulted in a series of project under a reseach collaboration agreement (including the spin-off Innoseis) and additionally in an STW project for developing a dedicated ASIC for their readout. The total cash and in-kind contribution of Shell in the period 2013-2016 has been around 1.5 MEuro.

Committee work with societal impact

- International Union for Pure and Applied Physics (IUPAP) P. Mulders (Liaison for the Netherlands) (2011-2012)
- Particle Physics Inside Products (P2IP BV): F. Linde (2011),
- Fonds Wetenschappelijk Onderzoek, Vlaanderen – Expertpanel Physics: E. de Wolf (2011-2016)
- Genootschap ter bevordering van de Natuur-, Genees- en Heelkunde: E. Koffeman (board member) (2015-2016)
- Permanente Commissie Grootschalige Wetenschappelijke Infrastructuur: F. Linde (2015-2016)
- Platform Bèta Techniek – Ambassador: F. Linde, E. de Wolf (2011-2016)
- Stichting Natuurkunde.nl: F. Linde (chair), M. Vreeswijk (editorial board) (2011-2016)
- Nationale Wetenschaps Agenda (NWA): S. Bentvelsen (2016)
- Stichting Physica: P. Mulders (treasurer)(2013-2016), E. Koffeman (2015-2016)
- Stichting Techniek Toernooi: E. de Wolf (chair) (2011)
- Top Sector High Tech Systems & Materials (HTSM) – Advanced Instrumentation / Precision Mechanics Board: J. van den Brand (2015-2016)

F.8.4 Institute for Theoretical Physics

Note: several other aspects of societal impact are mentioned in the main text.

Outreach: activities and strategy

The IoP organizes many outreach activities, in the form of master classes for excellent high school students, courses for high school teachers, popularization through lectures and through the Dutch popular physics web site www.quantumuniverse.nl, Open Days, the annual overview conference Viva Fysica! for physics teachers and their best pupils, help with 'profielwerkstuk' thesis projects for graduating high school students, and so on.

Our main strategy is to do research-inspired outreach: we want to show the general audience (and potential future students in particular) what the current open research questions are and why researchers are so excited about them.To make sure research and outreach stay closely connected, a special position was created in 2016 for a staff member to spend 40% of their time on research and teaching and 60% on outreach. This position is currently filled by M. Vonk, who does his research in the Institute for Theoretical Physics.

Now that several of the above activities have been set up, we are starting to look at ways to effectively evaluate the results of our outreach. The impact of outreach is notoriously difficult to measure, so we are in contact with Ionica Smeets, professor in Science Communication at Leiden University, in order to develop the most efficient tools for this. As a first example, we developed a new, updated brochure about the Theory Master in 2016, and will interview this year's new Master's students to see how impactful the new brochure has been. Similar evaluations for our other projects will follow, with the aim to keep our outreach activities as effective as possible, both in terms of 'conveying the message' and in terms of drawing new students.

- Books written by and media appearances of former ITFA staff member Sander Bais and prime time lectures on TV by former ITFA staff member Robbert Dijkgraaf. For an impression: search Youtube for 'Robbert Dijkgraaf'.
- A huge amount of media attention around the publication of the paper "Emergent Gravity and the Dark Universe" by Erik Verlinde including the 8 o'clock news; e.g. took part in television programmes like Labyrinth and did various on national radio interviews. For an impression: search Youtube for 'Erik Verlinde')
- Van der Schaar was chairman of the Amsterdam Science Festival foundation, which organized a pilot World Science Festival Amsterdam edition in 2013 that attracted over 7000 visitors (required fundraising of roughly 180k€).

Popular Scientific Publications

- Gianfranco Bertone published the book "Behind the Scenes of the Universe: from the Higgs to Dark Matter" that was translated into Dutch, French and Italian, and has won the "Ciel et Espace" 2015 prize for the best astronomy book. In collaboration with the London-based digital media company OtherMedia, Bertone also created the free "Dark Matter" app for iPhones and iPads, with a text adapted from the book, and enriched with images, videos and interactive content.
- Substantial international media attention (Quanta, Le Monde, NRC, Volkskrant ...) for the research of Miranda Cheng who will also write a semi-popular science book "A Small Book on Moonshine" (working title) with J. Duncan; a book contract has been signed with Princeton University Press.
- The popular science book "Zwarte Gaten, gevangen in ruimte en tijd" (*Black Holes: Caught in Space and Time*) by Marcel Vonk, to appear later this year with Amsterdam University Press.
- Verlinde/Vonk started the popular science website quantumuniverse.nl, to which ITFA members contributed more than 100 articles and blog posts.
- Popular science articles by various ITFA members in journals such as Nederlands Tijdschrift voor Natuurkunde, New Scientist, Physics World, New Scientist, Kijk.

Other

- The launch of the new free online open access (beyond Gold: Platinum/ Palladium 24 karat) scientific publication portal SciPost.
- Van Dongen was Guest curator, "Out of the box", Bijzondere collecties/ Universiteitsmuseum, University of Amsterdam, Spring 2016.

F.9 Conclusions and recommendations from previous assessment

The previous assessment report (2004-2009) is provided as a separate document and linked from Appendix . The assessment took place under a previous version of the Standard Evalation Protocol, in which the evaluated units were typically much smaller.

F.9.1 LaserLaB

The previous research assessment, of the VU Department of Physics and Astronomy, which covered the period 2004–2009, resulted in a very good overall judgment. Let us quote some of their finding: "*The academic reputation of the physics institute is internationally very high, and they are well-positioned within the Netherlands to work in three of the central themes in the Sectorplan: Physics of Life, Physics of Energy, and Physics of Light and Matter. These match quite well with the local strategy of VU to emphasize "Health and Life" and "Sustainable Earth/Energy/ Environment.". The Committee found good coordination with other physics institutes in the country through LaserLab Amsterdam and LaserLab Europe, where there are significant developments in metrology of use to the whole science enterprise*". Moreover, they clearly underwrote our collaboration plans with the UvA Physics and Astronomy. "*The Committee is very positive about the local coordination between VU and UvA. While they are maintaining their independent points of view, at the same time they engage in both joint research and joint educational programmes to the benefit of the whole country. The very recent decision to have overlapping academic programmes for the Bachelors degree is extremely positive. Harvard and MIT have been doing this for a number of years and the benefits to physics programmes are very strong*." Finally, the evaluation committee was impressed by our efforts to connect our science with society: *"The societal relevance of the education, the valorisation efforts and the outreach activities are highly appreciated."*

We felt encouraged by the previous assessment and have regarded it as strong support for our strategy to focus on specific themes within physics, to strengthen our collaboration and connection with UvA Physics and Astronomy (both in education and research). In the current evaluation period our societal connections and valorization efforts have considerably increased, resulting e.g. in several spin-offs and ARCNL, and ample public outreach, for example with respect to the first detection of gravitational waves (in which VU Physics and Astronomy researchers (van den Brand) have played a key role).

F.9.2 Van der Waals-Zeeman Institute

Overall the previous assessment was gave rise to very good/excellent grades and assessments. We highlight the most relevant observations and recommendations:

- Report page 81: "This group is among the leaders in the Netherlands in its specific field of research, and is well known, often invited to or active in organizing international conferences, but in the period under review not yet leading internationally. The productivity of the programme in terms of papers is very high, but continuously decreasing since 2004. The ability to attract external funding is sufficient to maintain the current level of research activities, but lacks highlights which would be visible beyond the Dutch borders."
    - The production is again at full speed; the decrease in number of publications was also due to the fact that Golden was director of the WZI; he has since 2012 been fully active in research again, and the results show. The level of funding and high-impact publications over this evaluation period is internationally (very) competitive.
- Report page 81: "An important issue remains the succession of Gregorkiewicz, which is currently discussed in the faculty. Here, an important decision has to be made between a further concentration of the research activities in this programme or trying to maintain a fairly broad activity spanning metals, semiconductors and dielectrics. The recommendation of the review panel is in favour of the latter."
    - In agreement with the recommendation of the panel, two novel TT'ers have been appointed in the group. Katharina Newell-Dohnalová's research focuses on quantum dots, and Erik van Heumen studies optical properties of quantum matter; these two new hires have strongly rejuvenated the group and keep the scope of the group broad. A broad-based recruitment process is currently being started to further strengthen the group.
- Report page 84: "This is a young energetic group with evident internal and external, national and international academic and industrial collaborations. The group is still growing in reputation and number of students. The group is small and will benefit from the addition of an equal quality tenure track position."
    - An excellent new young TT'er has been found and hired in the person of Corentin Coulais, who brings a new theme to the group: mechanical metamaterials.
- Report page 85: "Individually their accomplishments are equal to any but at present they don't have a big enough group to be competitive with institutes that have been set up in other countries."
    - As is discussed in detail below, two new hires have enlarged the group with several new activities.
- Report page 85-86: "Presently the Netherlands has not emphasized quantum gases as a priority research area and the group therefore must look to EU funding to continue. [...] Part of productivity is producing new funds in the form of FOM grants. Here we note that the long-term funding, headed by Walraven, seems about to run out in 2011. The appointment of a new professor in the team offers an opportunity to initiate a new FOM programme."
    - The rejuvenated group has been very successful in attracting both important EU and a large amount of national funding.

- Report page 85-86: “The magnetic chip work of Spreeuw and Van Druten is excellent and could constitute the real future for this group. Parts of the group seemed to have suffered from long-time absences and approaching retirements. […] A theoretical leader, Shlyapnikov, and an experimental leader, Walraven, will retire in the coming few years. The Committee felt that the preparation for these major transitions has been inadequate, with a search just commencing.”
  - Following the previous evaluation, the group has both be significantly reinforced and refocused. The existing staff (van Linden van den Heuvell, Spreeuw and van Druten) have focused their efforts on the magnetic chip work. At the same time, two new leaders have been attracted: Florian Schreck (as full professor) and Rene Gerritsma (as TT’er). These additions have substantially strengthened the group, and brought in a number of exciting new themes.
- Report page 86: “The Committee viewed the productivity of this group as low in comparison with the other experimental groups that we rated, in spite of the reasonably high bibliometric figures.”
  - The number of publications is still lower than the other experimental groups; however we are confident that after the previous build-up period, the new hires will be very productive, and the focused atom chip effort will bear its fruits. The year 2017 already shows a significant number of articles, published after the cut-off date for this evaluation.

F.9.3 Institute for High-Energy Physics

In the review period researchers took leading roles in large international experiments, culminating in substantial involvement in Nobel-Prize winning research such as the discovery of the Higgs boson and gravitational waves. These discoveries have also provided many opportunities for outreach via interviews, newspapers, TV coverage, as described in the appendices of the self-evaluation and also specified in the Nikhef annual reports. These leading roles were greatly enhanced by the leverage provided by Nikhef on infrastructure (e.g. technical support), international visibility (e.g. in organizing of conferences and workshops) and viability (e.g. enhancing the possibilities for hiring young talent). Concerning the role of conference proceedings, it must be noted that the collaborations are always represented at the in their field relevant conferences and workshops. As presentation at conferences are on behalf of experiments, the collaborations assign the actual speakers. Since most analyses are the result of dedicated teamwork, collaborations make an effort to ensure that especially researchers in the early stage of their career get the opportunity to present results on analyses to which they have made essential contributions. Amsterdam physicists are well-represented and further quantitative information can be found in the Nikhef annual reports. The remarks made in the Research Review Dutch Physics 2004-2009 with respect to viability remain valid, namely the complementarity of our programmes in collider physics (ATLAS, LHCb), astroparticle physics (KM3NeT, XENON) and gravitational wave research (Advanced VIRGO). The planning for these project for the next decade provides excellent prospects for research for our students and postdocs both for careers in academia and beyond.

In the period 2010 - 2016, the theory component in IHEF has become a very strong and vibrant theory group that broadly covers particle phenomenology housed at the Nikhef institute and ITFA. The full particle physics phenomenology group includes staff from the Nikhef Institute (NWO-I), the theory component of the VU section Particle and Astroparticle Physics (joint with the Nikhef Theory Group since 2012), the theory component in GRAPPA (established in 2011) and the particle phenomenologist of ITFA. The concentration of phenomenology in Amsterdam and its role as national center in the Netherlands has made it in a stimulating environment for postdocs, PhD students and MSc students, aided by the successes in obtaining collaborative grants via national FOM programmes and

EU Networking and individual grants such as three ERC Advanced Grants, two ERC starting grants and various other individual FOM/NWO and European grants. This results in of the order of 250 postdoc applications every year for (on average) 2 – 3 postdoc positions. The concentration of phenomenology strongly enhances the visibility and viability and also makes it easier to embark on outreach activities (performances, general talks and lectures, open days) and to coordinate educational efforts in the Bachelor, Master and PhD programmes.

F.9.4 Institute for Theoretical Physics

Overall the previous assessment was very good/excellent. We highlight the most relevant observations and recommendations from the previous assessment:

- Report p.78: “The University should continue to recognise and actively support the symbiotic relationship between the Particle Physics groups (UvA 4 and 6) and Nikhef.”
    - This relationship is recognized and was strengthened through the launch of GRAPPA and the hiring of Wouter Waalewijn and Daniel Baumann. There are still opportunities as mentioned in our strategy in A2: (i) Benefit from the recent discovery of gravitational waves: strengthen the link between Grappa, cosmology, high-energy theory and Nikhef through the intended hire of a gravitational wave astrophysicist and collaboration in the national science agenda (ii) Investigate possibilities to hire (possibly jointly with IHEF) and Beyond the Standard Model expert in line with a recommendation from our Scientific Advisory Panel.
- Report p.80: “PhD-students are very satisfied with their overall situation at UvA, however there were complaints about the - apparently, for students - very limited service and access possibilities for personal laptops. Terminal pools are space consuming, possibly inconvenient and seemingly outdated.”
    - This issue no longer exists. All students have their own laptops which they maintain themselves, the University providing an email account, various software licenses, wireless access (mostly Eduroam), and discounts on software and hardware via www.surfspot.nl.
- Report p.80: “The PhD council of the Dutch Research School for Theoretical Physics organizes an annual PhD-day. Such efforts should be encouraged and supported.”
    - This annual PhD-day still exists and still is successful. The IoP PhD/postdoc council organizes similar events at the IoP level.
- Report p.87 (evaluation of Particle Physics, Cosmology, Quantum Gravity): “The Committee, however, realised that most of the refereed articles are published in one journal only, Journal of High Energy Physics (JHEP), which has a viable impact factor of 6.0, but which is hardly known in physics branches outside of string theory and particle physics phenomenology. The Committee considered exclusive publication in a journal actually founded within this very same field to be too narrow and not to be of the very highest credibility. The Committee also recognised absence of summary and review articles about these fields, authored by members of this program, as another factor that led to reducing the very highest possible mark (a “5”) to “4” in order to account for these deficiencies, in comparison to other groups and programs regarded in the course of this review.”
    - While the string theory group still publishes a fair number of papers in JHEP (as do many other string theory groups around the world) more papers are being published in other journals such as Phys. Rev. Lett., JCAP, and Phys. Rev. D. The number of review and summary papers in this field is relatively small but we sometimes do write reviews as e.g. in the textbook “Inflation and String Theory,” by D. Baumann and L. McAllister, Cambridge University Press (2014), a review on the history of dark matter by de Swart, Bertone and van Dongen in Nature Astronomy (2017), the review “The moment of truth for WIMP dark matter” by Bertone in Nature in 2010, and in various lecture notes and

proceedings of schools.

- Report p.91 (evaluation of Quantum matter and Complex Systems) "Specific recommendations to achieve this include: continued efforts to strengthen the complex systems and collective phenomena focus area, through new faculty (currently a search is planned) and through the special mechanism of extraordinary professorships."
  - Edan Lerner was hired to strengthen this particular area, but with the retirement of Nienhuis and the failure of the merger of the UvA-VU physics departments this focus area is threatening to become subcritical again. Our strategy here is as described in A2: unite Theoretical Physics Amsterdam in one strong institute (division) at uni-location, esp for soft matter/bio theory, vs critical mass (i) strengthen the collaboration with the VU soft matter theory group, (ii) strengthen the collaboration with the soft matter experimental group at WZI, and (iii) look for collaborations with other groups at Science Park, in particular at AMOLF. Regarding professorships by special appointments, we have not been able to attract someone in this field yet but plan to intensify our search in the upcoming years.

F.10 Other relevant documents

This appendix contains links to additional relevant documents pertaining to this self-evaluation. All documents can also be found on **iop.uva.nl/evaluation**.

F.10.1 Bibliometric analysis of UvA and VU Physics

The university libraries of UvA and VU have carried out a bibliometric analysis of all publications over the period 2007-2016, based on the publication output registered in the shared management information system Pure. The analysis was carried out using Web of Science tools. The report can be found here.

F.10.2 Relevant policy documents

VU Policy document on data management
VU prioritizes the careful handling of research data, which, in a time of digital output, is more important than ever. The university has therefore compiled the Research Data Management Policy, which provides guidance for researchers and policy makers at the VU. It can be found on the VU website.

IoP Code of Conduct on Scientific Integrity
In close consultation with the IoP PhD/postdoc council, the IoP directorate has formulated a code of conduct on Scientific Integrity that can be found on the IoP website.

F.10.3 Conclusions and recommendations from previous assessment

The previous physics research assessment covered the period 2004-2009 and was carried out at a national level for all Dutch universities at once. Under the previous version of the Standard Evaluation Protocol (SEP), the size of research units was typically much smaller than in the current SEP.

The sections from the national assessment report relevant to UvA and VU can be found here.

F.10.4 Recommendations from mid-term review (IoP)

At the UvA's Faculty of Science, all research institutes have an international Scientific Advisory Panel (SAP), which can be consulted either by the Dean or the institute leadership on an ad hoc basis, as well as for a mid-term review halfway through the regular SEP evaluation cycle. The IoP's SAP has visited the institute in October 2016 for a (belated) mid-term review, the report of which can be found here.

F.10.5 Other relevant self-evaluations

F.10.5.1 Nikhef evaluation 2011-2016

Since the IHEF research unit in this self-evaluation is tightly linked to the national institute for subatomic physics Nikhef, the self-evaluation document of the latter for their 2011-2016 SEP evaluation is provided here.

F.10.5.2 ARCNL self-evaluation 2014-2016

Because of the tight links between LaserLaB and the WZI on the one hand and the 2014-founded Advanced Research Center for Nanolithography (ARCNL) on the other, the self-evaluation document of the latter for their 2014-2016 SEP evaluation is provided here.