

Institution: University of Hull

Unit of Assessment: 9 Physics

1. Unit context and structure, research and impact strategy

1.1 - Unit Context

The Hull Physics activities at the University of Hull are situated in the Department of Physics and Mathematics, which was re-established as an independent Department in 2014 following a period of operating within Physical Sciences. The core values of the Department are centred around inclusivity and our importance as a regional anchor institution with a global profile. Those values have guided our efforts in every aspect of our research and impact strategy. This is highlighted by our recent “Changing Face of Physics” campaign (Fig. 1), which has already been recognised at the national level, as well as our national and international outreach and education efforts, and our regional recognition as a highly technological talent pipeline for key industries. Further impact is leveraged by WRIPA+ (White Rose Industrial Physics Academy), a £5.6 million grant led by the Hull Physics to improve our students’ access to industrial partners through internships and training.

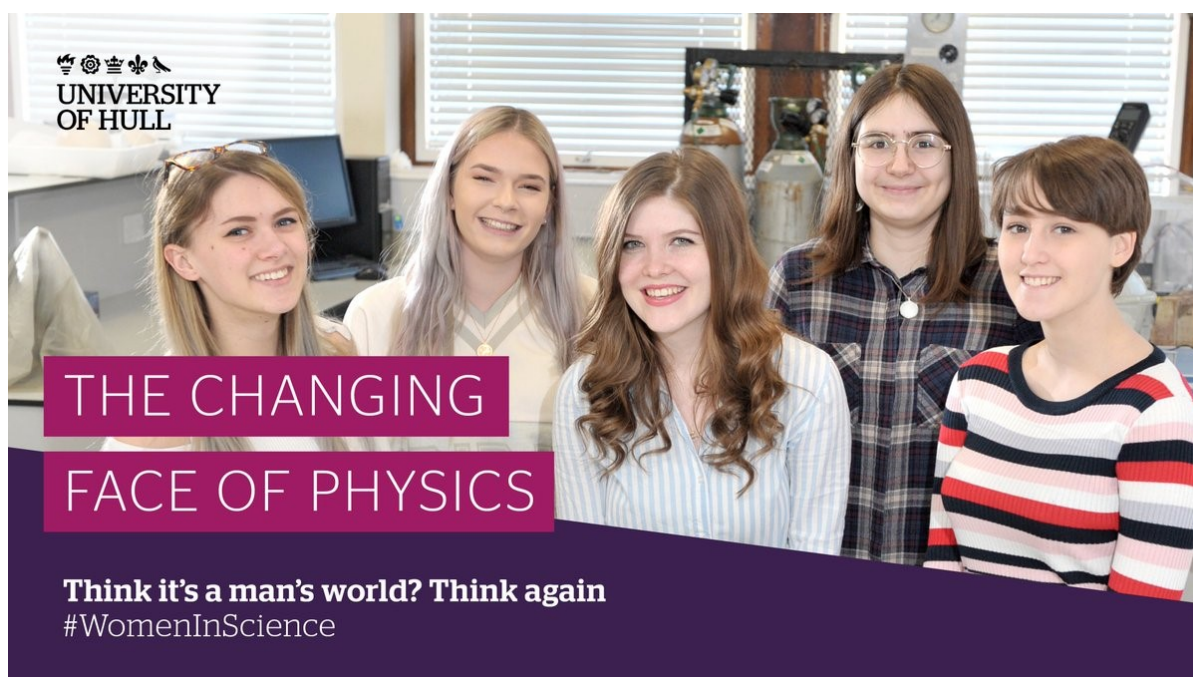


Fig. 1: Illustration of the Changing Face of Physics campaign pioneered by Hull Physics

The current external funding portfolio consists of approximately £3M in the REF period, including awards from UKRI (EPSRC, STFC, MRC), EU FP7 and Horizon 2020 (FET Open, MSCA), Innovate UK, KTPs, industrial sources, and charities (Leverhulme, Royal Astronomical Society; Ferens Educational Trust). The unit has published 409 peer-reviewed papers in the period.

Our efforts have far-reaching impact on social welfare: from the products and services developed by our team, to outreach and education of the community. Furthermore, the innovation pioneered by our research impacts on the social welfare of the region and attracts companies that want to establish working relationships with us. Project AURA, an umbrella vehicle for multi-disciplinary research-engagement and commercialisation opportunities for University researchers to

collaborate with manufacturers, developers, operators, skills providers, universities, government and others to drive innovation in the offshore wind and wider low carbon sectors, embodies this impact.

All funding agreements incorporate investments into university infrastructure that allows us to train and nurture the next generation of innovators. In the meantime, the knock-on effects of having experts living and working within the region creates tangible benefits to the tax base.

Our emphasis on igniting passions and ambitions, outreach and interactive demonstrations for school children showcase the ongoing innovation and inspires them to succeed in their own lives. Such activities impact on social welfare, since it helps to raise the aspirations of poor and disadvantaged students, enabling them to succeed through learning and discipline.

1.2 - Unit Structure

Hull physics and mathematics activities are grouped under a single Department of Physics and Mathematics. The two units are managed by a single head of Department (Gibson) and three deputies (Pignatari, Roediger, Dommers) with responsibility for research and teaching, alongside a director of postgraduate research (Kemp).

The unit consists of two primary research Centres, addressing three research themes (**Astrophysics**, **Laser physics**, and **Nanotechnology**) and 11 members of staff with responsibility for research. It has built itself up from a low base to launch the E. A. Milne Centre for astrophysics and to contribute strongly to the interdisciplinary G. W. Gray Centre for Advanced Materials (covering laser science, and nanophysics, nanotechnology, and nanostructures: the Nano³ group). Since 2014, Hull Physics has employed six new research-active members of staff and undergone a university investment of approximately one million pounds in buildings and infrastructure. Moreover, two additional applied Mathematics lecturers have just been appointed, with a strong overlap with Physics (Blackhole physics/quantum field theory, and applied statistics, mathematical biology applications/biophysical modelling/pollution distribution around building).

This structure enables a cross-fertilization of ideas between the two disciplines and has led to jointly-run, research-led postgraduate Masters degrees, and joint seminars on research topics that add breadth to both disciplines. The Department sits within the Faculty of Science and Engineering - one of four faculties in the university.

The research staff during the entire REF period, including colleagues past (in brackets) and present, are split into the two groups as follows:

- **Milne Centre** (astrophysics): Benoit; Gibson; Pignatari; Pimbblet; Roediger; Zharkov; (Chongchitnan); (Reid-Edwards)
- **Gray Centre** (Laser Science and Nanophysics): Adawi; Buzza; Bouillard; Kemp; Snelling; Verrelli; Walton; (Emary); (Dyer); (Dyson); (O'Neil)

The **Milne Centre** focuses on a breadth of astronomical problems under the umbrella topic of “*origins*” that ties directly to STFC’s roadmap for frontier sciences on the origin and evolution of stars and galaxies, as well as the origin of elements in the Universe. Building up from no staff, the centre features a vibrant mixture of computational astrophysics complemented by observational expertise in large format, multiwavelength survey astronomy.

In parallel, Hull Physics' contribution to the **Gray Centre** focuses on EPSRC's themes of *manufacturing the future* and *physical sciences* and, through its applications, it contributes to all four prosperity outcomes (productive nation, healthy nation, resilient nation, connected nation). Within the Centre, our applied laser scientists take a functional physics approach - directly applying knowledge of light-matter interactions to problems identified by industrial partners. In parallel, our nanotechnology group (Nano³) covers complementary expertise in nanoelectronics, nanophotonics and nanomaterials. These directions interact strongly with key applications such as artificial intelligence, optical computing, innovative sensing solutions for medical and environmental needs, in concert with novel self-assembly approaches that address currently unanswered challenges in nanofabrication.

Non-research staff also supports the activities of the unit: Ingham, Alanson, (Kelly), (Sands), (Urquhart).

1.3 - Research and Impact Strategy

1.3.1 – Research strategy

Our research strategy is aligned along three major axes:

1-Astrophysics (Milne Centre):

The unit strategy for the E. A. Milne Centre is to bring together experts in computational and observation astrophysics to address some of the big questions of modern astronomy on how galaxies and stars form and evolve over cosmic time, as highlighted in the STFC roadmap on origins (<https://stfc.ukri.org/research/science-challenges/>). The international standing of the Centre is shown by its direct participation in many international institutes (e.g., GAMA and JINA-CEE), and by the leading roles played by its members in large research networks (for instance, in the US IReNA, the European ChETEC-INFRA, the NuGrid collaboration, TAIPAN, LSST).

2-Laser Physics (Gray Centre):

The laser group at the University of Hull, established in 1968, is a long-term and successful research theme in Hull Physics. The research strategy of the group is to probe the interaction of light with matter for scientific, industrial and medical applications. This primarily involves laser sources - hence the group also studies the generation and delivery of high intensity light. The Hull Physics' laser expertise is represented across the university by Snelling's role as University Optical Safety Officer.

3- Nano3 group (Gray Centre):

The Nano³research grouping was established in 2016 out of an Organophotonics research group. It focuses on three complementary aspects of nanotechnology: nano-materials, nano-electronics, and nano-photonics. The group's strategy is to bring together highly complementary experimental and theoretical expertise to create and develop future technologies addressing key societal problems in the areas of energy, information storage, ICT and health.

Furthermore, we feature a wealth of interdisciplinary and internal interactions that include, but are not limited to, Chemistry, Biology, Biomedical sciences and computer science. The synergy between the three themes is strong, with staff interactions maximising the productivity (e.g. Benoit's activity in astrochemistry/astrobiology straddles both the Milne and Gray Centres; Snelling and Roediger collaborate to apply plasma simulation codes to simulating laser ablation

plumes). Additionally, there are natural interactions between the Laser Physics group and the Nano³group.

In parallel, research from Hull Physics strongly supports and impacts other units of assessments in the University. In addition to many cross-disciplinary papers with Chemistry, Biology and Biomedical Sciences, Physics research has directly supported impact case studies in UoAs 8 and 12, where Snelling and Kemp's activities have contributed to the underpinning research.

1.3.2 – Impact strategy

Our **impact strategy** builds on the effective partnerships we develop with research-users. We focus on direct applications and industrial conversion of research to business, outreach and education. For industry, close links with industrial partners have produced a variety of KTPs, patent applications, material exchange (e.g. proprietary polymers, and dyes). For outreach, the Milne Centre uses its research outputs to train the next generation of students in coding, observation, and teacher training. An example is the ThaiPASS project (see Fig. 2) that delivered two summer schools on Python programming for Astronomy in 2018 and 2019 (with two additional schools, 2021-2022). Our PhDs and PDRAs play crucial roles in these activities via demonstrations and contributing to guest lectures.

The **Aura Innovation Centre** (AIC) recently opened at the Bridgehead Business Park on the outskirts of Hull. It is a £12M investment of University and European Regional Development Funding and provides space for large businesses and SMEs to access University research for collaboration and innovation, and in the offshore wind sector especially. It also houses dedicated Aura Innovation Managers, research labs and equipment that connect commercial users with university expertise to support shared activities, development and commercialisation (including projects supported by an £8M ERDF-fund of University-administered Sparkfund Innovation Vouchers and Research and Development grants).

The University Directors of Business Engagement and Enterprise support this infrastructure, as does a Knowledge Transfer Partnership (KTP) Champion and dedicated KTP support. Transparent university support also includes HEIF funding (through application with an external user), dedicated Impact Officers and Impact Accelerator Awards also support this agenda.

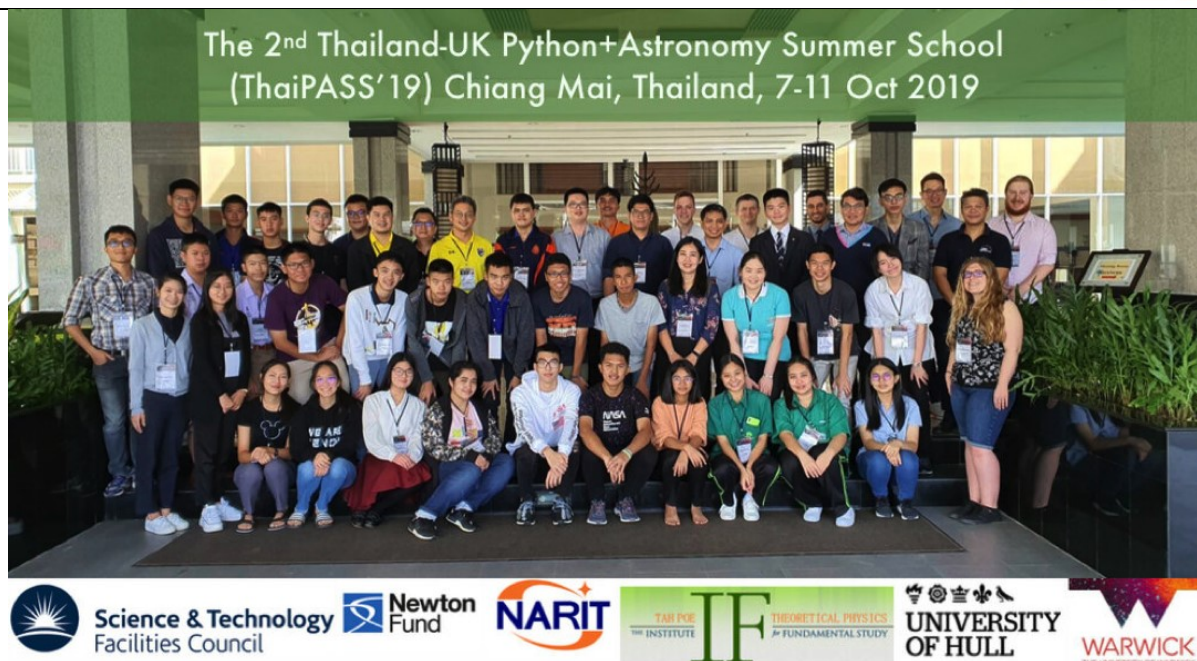


Fig. 2: Summer School picture of our ThaiPASS python and astronomy summer school (2019)

1.4 - Achieving impact through case studies

Our national and international outreach and education efforts, and our regional recognition as a highly technological talent pipeline for key industries, are each showcased in our impact case studies.

The outreach case study highlights how our research facilitates creativity, builds skills, and ultimately enhances society via activities that target under-represented groups and socio-economically disadvantaged regions. Our “Changing the Face of Physics” initiative doubled the number of women studying Physics at Hull, and we supported over 100 school teachers and provided over 30 work experience opportunities to under-represented groups. This activity contributes to the UK’s Industrial Strategy by inspiring, engaging and, for some, training a STEM- and digitally-literate workforce.

In parallel, our Laser physics group takes a functional physics approach to laser physics and light-matter interactions: applying it directly to problems identified by industrial partners (e.g. Luxinar Ltd., The Welding Institute, BOFA Ltd.). We have enabled the launch of a new laser system, generated novel laser-based processes and diagnostics, and produced a high-quality workforce that supports the UK laser industry. Additionally, we have generated a talent-pipeline that transitions alumni into laser-based industries which supports the UK National Strategy for Laser-based Manufacturing. Our longstanding cooperation with laser companies in our region also underpins the UK’s capacity for this key industry.

1.5 - Research objectives over the next 5 years

Hull Physics’ research objectives over the next five years will continue the development of its research themes, further strengthen our position as an anchor-institution, and continue our efforts towards inclusivity in STEM. We will achieve our stated vision through outreach from the Milne Centre and innovation via the Gray Centre.

We will increase our cross-disciplinary activities, aligning closely with institutional strategic investments such as AURA EPSRC Doctoral Training Centre, the EEI (Energy and Environment Institute), Biological Sciences, and HYMS (Hull York Medical School). Many of our staff are also naturally interdisciplinary: our latest departmental appointment (Jie Yang, appointed 2021) is a world leader in pollutant dispersal modelling and applied epidemiology studies, and has already established links with AURA). We will be supported by four further appointments in applied mathematics in 2021.

In Astrophysics we will expand our theory/computation research base in exoplanets. Exo-planet research is currently the clear missing-link in our research provision and the single-most important science driver for all major UK and EU infrastructure investments (as evidenced by our £1M in EU grants awarded in 2020 (Project name ChETEC-INFRA)).

One major initiative to note is Hull Physics' participation in 4MOST, a four meter class multi-object fibre-fed spectroscopic facility for survey astronomy that will be mounted on the VISTA telescope (ESO). It has a huge multiplexing advantage capable of obtaining 2400 targets over four square degrees simultaneously. This facility will cover the entirety of the Milne research ranging from Galactic disk studies and the origin of the elements in the Milky Way (Gibson, Pignatari, Benoit) through to extra-galactic science in large-scale structure and galaxy evolution (Pimbblet, Roediger, Gibson). Hull Physics' involvement in this facility will generate outputs and impact for our next REF, and it will open opportunities to join prominent European observational projects in the next decade.

The visions of the Laser physics and Nano³ groups respond to the Industrial Strategy, the Wakeham Review, and UK and EU funding priorities, as highlighted by a current EU Horizon 2020 FET Open project POSEIDON (Jan 2020: Buzza, Adawi, Bouillard) which is a £3.07M European Project to develop a new platform for on-chip light sources in photonic integrated circuits (<https://poseidon-fet.eu/>).

For Laser Physics, the UK Roadmap for Laser-based Manufacturing, published by the EPSRC CIM-LbPP and Association of Industrial Laser Users, calls for an increase in the use of lasers in manufacturing for the UK to compete internationally. Hull contributes to this roadmap through our interactions with industrial partners. The same roadmap also identifies "Fundamental laser process science to improve the understanding of laser-material interactions" as a key priority. This is a core approach of Laser Physics in Hull (as one of the most important underpinning technologies and R&D priorities).

For Nano³, smart materials, manufacturing, nano-photonics will consolidate existing strengths (organophotonics, nano-sensing, soft-matter physics) as well as support and complement various AURA programmes and EEI directions. Additionally, medical physics (acknowledged by the APS and IOP as possessing significant growth potential) is developing as one of our areas of strength (Adawi, Benoit, Bouillard, Kemp). Consequently, we will continue to nurture our strong links with the NHS Trust, which have led to three PGR students working with local hospitals (Castle Hill Hospital, Cottingham), including the country's first Jocelyn Bell Burnell Graduate Fellow (Kiri Newson).

A further area of strength is the development of neuromorphic nanodevices and architectures, where two new grants were recently awarded (Kemp): EPSRC – Special Call – Hardware for Efficient Computing (EP/V028057/1), and a Leverhulme Trust grant (RPG-2021-115).

In parallel, outreach remains one of the key elements in our strategy and Hull Physics accounts for the majority (>50%) of the University's outreach (as per HEBCI returns), and we will continue to develop this aspect of our core values around inclusivity and our importance as an anchor institution.

We will be looking to appoint new research active staff and support staff (e.g. outreach project officer, laboratory experimental officers) along those lines.

1.6 - Open research environment and research integrity culture

Hull Physics staff (Pignatari) coordinate the NuGRID collaboration (www.nugridstars.org), an open, flexible collaboration involving researchers from institutions from UK, USA, Canada, Italy, Germany, Spain, Australia and China. NuGRID's code of conduct, access to codes and use of public products are regulated by the manifesto (<https://nugrid.github.io/content/manifesto>).

Both the Milne Center and NuGrid are actively engaged in IReNA (International Research Network for Nuclear Astrophysics), for which the code of conduct regulates the mechanisms allowing to share research and research data openly as appropriate to the discipline, according to the APS guidelines for professional conduct and the AAS research Code of Ethics (<https://www.irenaweb.org/code-of-conduct.html>).

Additionally, several members of Hull Physics are part of the European H2020 project ChETEC-INFRA (awarded in November 2020). It specifically aims to develop open-source codes and broadcast research and knowledge across Europe and the UK. The project will unify access to trans-national nuclear-astrophysics research infrastructures using a novel integrated web portal. It will develop improved nuclear reaction targets and detectors, open-source nucleosynthesis software tools, and three-dimensional model atmospheres for stellar spectral analysis. This EU project is linked to nuclear astrophysics communities in the United States, China, and Japan.

The unit is committed to ethical and research integrity. All members of staff undertake mandatory ethics training. All research undertaken in the Faculty is recorded on the University research management platform (Worktribe) and needs ethical approval. Any sensitive aspects are discussed and reviewed by the Faculty Ethical Committee, and no research begins without ethical approval.

2. People

2.1 - Appointment of new staff & Staffing Strategy.

Since 2014, five staff have retired or left the department and we have appointed seven (six research active and one on the teaching stream) new permanent members of staff in physics at all levels from Lecturer to full Professor.

The primary staffing activity during the REF2021 assessment period was the establishment of an astrophysics stream alongside physics, with the appointment of five long-term astrophysics

staff (four REF-eligible and one on the teaching stream). All four REF eligible staff have been returned here. Undergraduate recruitment into astrophysics is increasing and is likely to lead to additional posts being released within the next two years in this area.

In the same period, there have been eight promotions within Hull Physics. Our 14 full-time academic staff, three PDRAs, and 30+ doctoral students (on average more than two PhD students per staff member) represent more than a doubling of Hull Physics staff since REF2014 (when physics staff were returned under Chemistry and Engineering). Appointments have been made across all of our primary research areas in the REF period.

A shift in skills focus into Data Science, AI, and machine learning has led to increased synergies with the medical physics community within the regional NHS Trust. We anticipate further expansion into this area that complements research already undertaken in machine learning/AI/neuromorphics within physics and astrophysics streams.

We will aim to develop key areas through the appointment of at least one chair in experimental physics and one in theoretical/computational physics. Both appointments will sustain leadership across our three strategic research themes. These appointments will be further complemented by a minimum of three ECA/mid-career posts to further develop existing strengths.

2.1.1 - Astrophysics

The E. A. Milne Centre for astrophysics was established in October 2015 and has grown to seven full-time members of staff, two post-doctoral researchers, and 25 postgraduate students as well as three honorary members (Helen Sharman, Jocelyn Bell-Burnell, and Martin Rees). The Milne Centre director is Gibson (2015) who was supported directly through a newly created Milne Centre research fellow (Few, 2015 to 2019).

The centre has been enhanced by the appointments of Benoit, Pignatari, Pimblet, and Roediger (all promoted in the period) to create a broad expertise centred around computational astronomy, coupled with strong observational expertise in areas involving galactic and extra-galactic astronomy and cosmology, through to nuclear astrophysics and astrochemistry. Through external funding we have hosted world leading experts (e.g. Prof T. Beers funded for six months through a Leverhulme grant) to enhance our capabilities during the period, and the centre has been a focus of investment for the period by the University.

2.1.2 - Laser Physics and Nanotechnology

In parallel to the E. A. Milne Centre, the G. W. Gray Centre for Advanced Materials was established in September 2016 (named after Professor George Grey who developed liquid crystals materials science at Hull). It encompasses the activities of the Laser Physics and Nano³. This covers seven permanent members of staff, with two (Verrelli and Bouillard) appointed during the REF period to enhance pre-existing strengths in laser physics and nanotechnology research. Four staff were promoted in the period (Adawi, Bouillard, Buzza, and Kemp). Amongst other visiting members, we have also hosted Prof. Sir Michael V. Berry (H. H. Wills Physics Laboratory, University of Bristol) as part of a Leverhulme grant.

2.2 - Staff Development

Hull was awarded the HR Excellence in Research Award in 2012 in recognition of its commitment to promoting the principles of the Concordat to Support the Career Development of

Researchers. Since then, the award has been renewed following an internal review in 2014 and an external audit in 2016. The Faculty and University have introduced several schemes to directly support the career development of all staff (encompassing the full range of academic, professional services, and technical support staff).

The University recognises the importance of work-life balance and offers a range of benefits including up to 76 weeks of maternity or adoption leave, as well as paternity leave, parental leave, dependants' leave, carer's leave, leave for fertility treatment and the option to request flexible working. Balancing the competing needs of the unit is achieved through a workload model, which protects the research time of staff with responsibility for research.

To develop new research directions and support existing ones, the Faculty of Science and Engineering introduced the Research Support Fund (up to £250k per annum in the period) that all research-active staff members can access. This covers all research activities from conference presentation, through research visits to equipment purchases. Every member of staff in Physics has been supported through this scheme in the REF period. The scheme especially encourages applications from early career academics and those returning from parental or sickness leave. The scheme can make extra provision for parents with dependents if required. It also provides support specifically targeted at PDRAs for activities reaching beyond the funded grant that employs them – to allow them to further their personal research profiles from their PhD research, or a previous, or potential, Post-doctoral position.

All staff are allocated mentors for both teaching and research in order to develop their profiles. Mentors undergo specific training (AdvanceHE) provided by the University to facilitate these roles, and mentors can be drawn from diverse areas of the university to serve different needs. This has yielded cross-disciplinary exchanges directly (e.g., in the area of computer science and machine learning) which have directly benefited Hull Physics in terms of new bids for external and internal funding (e.g., STFC citizen science bid).

Grant writing skills are developed through the Grant Writing Challenge, whereby university Research Development Managers and senior colleagues guide a cohort of early career academics through a structured, six-month series of sessions to produce a competitive grant application. ThinkWrite Grant- and article-writing workshops are also held annually.

Writing Retreats are supported in various forms. The Faculty had a member of staff trained as a Writing Retreat facilitator (by AdvanceHE) and day retreats on and off campus are supported. Writing retreats are very productive and popular with some staff (often women and early career academics), which is why they continue to be supported.

In 2017 the Faculty introduced annual research awards to recognise research and engagement activities. Seven categories stretched across all career stages, roles and collaborations, as well as leadership. These events are catered and build excellent research culture.

Career development, continual professional development, and training for staff is provided via annual performance reviews and specialised university courses. This includes mandatory participation in training for inclusivity and diversity, research ethics, occupational health and safety governance, GDPR, corporate manslaughter and the law, project management and leadership courses (e.g., Aurora was undertaken by Roediger, AdvanceHE research team leadership was

undertaken by Benoit), and support for sabbatical leave (Kemp, Chua Memristor Center-TU Dresden, 2020).

New lecturers in their first post are additionally supported through a reduced teaching load, combined with teaching training (Postgraduate Certificate in Academic Practice), incorporating graduate student supervision training. Further research training opportunities are provided by bespoke writing retreats (to help complete papers, or grant applications, etc.), and compulsory internal peer review of all grant applications to improve success rates.

Hull Physics has a strong record of national and international visiting staff supported through the Department, Faculty, and national competitive grants. This has led to new collaborations and the expansion of existing ones to provide new research directions and grant bids.

In addition, staff within the unit have held visiting status at other institutes during the REF period (Gibson was adjunct professor at Universidad de Granada, 2014, and distinguished professor at Hungarian Academy of Science, 2015-2016; Bouillard was visiting senior researcher at King's College London 2014-2017 and visiting scientist at University of Technology of Troyes, France in 2018; Pignatari was an honorary associate of Konkoly Observatory, Budapest for the period; Pimblet was adjunct senior astrophysicist at Monash University, Australia 2014-2016; Kemp is Visiting Senior Research Fellow at the Chua Memristor Center (2020-present). These appointments all led to research outputs, and additional students undertaking research at Hull during exchange visits.

2.3 - Materialising impact from staff research

To enable staff to maximise the potential impact of their research, the unit has a dedicated industrial liaison officer (Ingham) who facilitates collaboration with industrial contacts within the WRIPA+ £980k grant. The unit also has access to the AURA Innovation centre's specialist impact personnel, such as its two Innovation Managers, to business and commercial support from the Enterprise Centre, and assistance from an IP office to explore and protect the intellectual property of promising scientific results.

In addition, the University supports Outreach and training activities to promote research and disseminate key results through a range of services, including dedicated School liaison office, and Outreach events organisation.

2.4 - Research Students.

2.4.1 - Recruitment and Funding

We currently have over 30 post-graduate research students (with around three new students every year). They are recruited from a plurality of sources that include University of Hull funded thematic clusters of PhD studentships, research council funded doctoral students (e.g., STFC), European funding (Horizon 2020), external government funded students (notably several Iraqi students), joint PhD funding from the University of Hull and external sources (e.g., Hungarian Academy of Sciences, the French FEDER (European Funds for Regional Development)), plus self-financing students from the UK. Notably, in 2020, Kiri Newson won one of four prestigious IOP Bell Burnell Graduate Scholarship Fund, aimed at addressing EDI in the UK physics landscape, enabling her to pursue a PhD in Artificial Intelligence in Medical Physics (Benoit) in collaboration with NHS Castle Hill Hospital.

Additionally, the University invested in a joint PDRA position, supplemented by external funds from LABEX (LABoratory of EXcellence) in France. Approximately 15% of our postgraduate students in the period have been non-UK in origin.

The PhD clusters funded by the University of Hull are up to six studentships and are designed to develop areas of existing or potential strength in the University. Hull Physics has had repeated success under this scheme with the Milne Centre and the Gray Centre both receiving multiple awards, with 18 studentships across nine clusters covering topics such as medical physics, 3-D printing, environmental sensing, astrophysics, and big-data.

A further strand of summer studentship schemes is funded by the University and by external funders (Royal Astronomical Society, Rank Prize Funds Summer Vacation Scholarship, Royal Society of Chemistry). These have led to an increase of students undertaking PhDs at Hull and externally.

Additionally Hull Physics is an active partner in the new international Nano-Phot Graduate School (official Hull contact - Bouillard), which includes partners across the academic and industrial sectors from North America (USA and Canada) to Singapore via Germany and Russia (<https://nano-phot.utt.fr/partners>), and benefiting both nanotechnology and lasers research themes.

2.4.2 - Training and Support

All postgraduates are supervised by a minimum of two academics and are required to undertake 60 credits (PhD) or 20 credits (MSc) of taught courses with the universities' accredited credit system - a postgraduate training scheme run via the doctoral college of the University.

The courses offered provide core training (modern research topics, ethics, health and safety, leadership, communication skills), and are tailored to students. Each 20 credit module features up to 40 hours of contact, and beyond the compulsory modern research training; modules can be selected in agreement with student supervisors from a portfolio of HE7 offerings across the university (e.g., computer programming modules in specific languages, cutting edge research topics from capstone astronomy, nanofabrication and nanophotonics, topics in data science). In order to enable postgraduate students to discuss any aspects of their PhD degrees and corresponding taught elements, a postgraduate staff-student forum has been established (2018).

Training is supplemented by an initial induction process, and annual research days where each student is required to present either a poster or a talk, and to participate in open question and answer sessions about topics such as the summative viva at the end of the degree. All students are given access to bespoke research areas to conduct their work. They also have access to the specialist seminars run by the research centres within the unit, plus the regular Hull Physics seminar series. To ensure full engagement with the speakers, we run a postgraduate question time at the end of each presentation wherein academic staff leave the venue and the students ask their questions to the speaker uninhibited by the presence of senior colleagues.

Specific training in lab equipment and supercomputer access is given on requirement. In view of their importance for post-graduate students' scientific development, during the pandemic those seminars were immediately moved to online delivery, while retaining the question and answer format, ensuring their continuity. Other responses to Covid-19 disruption included funded

extensions for PhD students (and PDRAs if needed), support with IT and workstation equipment for researchers working off-campus, and additional research Culture and Community Seminars to sustain the research environment while normal university conditions were suspended.

Finally, we note that our postgraduate cohort has a strong involvement in our outreach culture and are regularly invited to assist with observing evenings, A-level and GCSE enhancement sessions for schools, as well as giving talks to further the public understanding of science. This activity enables our graduates to develop a wider understanding of how to disseminate their own work and improves their career prospects, as well as strengthening our Anchor University role for local communities.

Postgraduate progress is monitored through the use of formal monthly reports driven by the students and agreed to by supervisory staff member, and annual progress reports and viva at the end of the first and second years of the degree. This enables rigorous and supportive feedback to the students and ensures their readiness for the summative viva examination at the end of the degree.

2.5 - Equality and Diversity

Equality, diversity, and inclusivity are underlying principles of Hull Physics. Together with colleagues in chemistry and mathematics, we established an Athena SWAN committee in 2016 with representation deliberately sought from all grades of staff contract, all levels of seniority, and a balance of gender. We have embedded practices to:

- promote gender equality within the unit and beyond
- ensure a 50/50% gender ratio for invited speakers in departmental events (e.g. seminars, conferences, summer schools)
- deliver unconscious bias training and Equality and Diversity training for all staff carrying out interviews
- ensure that all publicity is adequately gender balanced
- ensure workload model transparency for all staff
- identify staff ready for promotion

These policies and practices were implemented with the feedback obtained anonymously from staff and student cohort surveys. This led to a Bronze Athena SWAN award in 2018, for which Hull Physics was cited at a national level for good practice for our “Changing Face of Physics” marketing campaign. This campaign focussed on creating a step change in the proportion of women taking physics degrees. It dramatically improved the percentage of female undergraduates from significantly below the national average (13% in 2014) to significantly above (26% in 2017) in the span of a few years.

We are currently collecting further EDI data to support our Silver Athena SWAN submission, and have established a committee to oversee the process, identify and implement the necessary adjustments to our existing unit policies. Our efforts will focus on protecting staff work-life balance and further supporting staff family commitments and childcare such as:

- a flexible working policy that acknowledges family life, with key meetings within 9.00am-3.00pm
- workload that is proportional to FTE (so part time staff are not disadvantaged)
- establishing EDI, and Health, Safety and Wellbeing as standing agenda items on all formal meetings

3. Income, infrastructure and facilities

Over the REF period, Hull Physics has secured over three million pounds of external grant money (direct income to the unit). This was enhanced by approximately one million pounds of University budget to build our capacity in people, infrastructure and facilities. Hull Physics infrastructure is spread over three buildings on campus and is grouped thematically according to our research specialisms.

3.1 - Income

Notable grants (over £300K of direct income to Hull) include:

- EU POSEIDON (EU-H2020-FET-OPEN)
- ChETEC-INFRA (EU-H2020)
- INFINITY (EU-H2020-SC-Climate)
- SelfAssembly of two dimensional colloid (EPSRC)
- Monodomain Organic Semiconductors (EPSRC)
- Astrophysics at the University of Hull (STFC)

In addition, we have been successful in obtaining smaller, non-UKRI funding in a number of areas, including:

- EU-COST (25k; Adawi, Bouillard, Pignatari)
- Ofqual (5k; Snelling)
- Spanish ministry (85k; Gibson)
- HEFCE / HEIF (62k; Kemp; Pimbblet, Bouillard; Snelling)
- Royal astronomical society funding for running NAM (25k; Milne Centre)
- Ogden Foundation (30k; O'Neill, Pimbblet, to fund Urquhart's position)
- Innovate UK (125k; Snelling; Kemp)
- Leverhulme (200k; Gibson, Snelling)
- ERDF (16k; Verrelli, Walton) through the AURA Innovation Center
- Industrial investment and sponsorship (120k from Rofin Sinar UK for Snelling, 60k from Tyco for Kemp).

Complementing this research income, Hull Physics has benefitted from the **collaborative use of research infrastructure and major in-kind contributions**.

The "*Horizon Run 5*" high-resolution simulation captures the key galaxy formation physics, while modelling the large-scale structure of the Universe. The simulation enjoyed a 350 Mcore-hr in-kind contribution from KISTI (Korean Institute of Science and Technology Information) on their new HPC facility, valued at ~£3.5M.

Hull Physics' collaboration with Luxinar Ltd. (a leading Laser manufacturing company) led to an in-kind contribution of a loan of a £140k laser, as well as the donation of two carbon dioxide lasers (~£10k). The Physics laboratories also received a fume extraction unit from BOFA International Ltd (~£1.5k).

Other significant facilities include external clean rooms (UTT, France; Bouillard, Adawi); Supercomputing facilities (Westgrid, Canada; Hungarian HPC NIIF; Pignatari; EU PRACE/DECI HPC; NRAC, Canada; Gibson); and observatories (AAT, 2m Siding Spring; Pimbblet; HST, Pimbblet and Roediger; Chandra, IRAM, VLA, Roediger; UKST, Gibson, Pimbblet).

3.2 – Infrastructure and facilities

Within the faculty strategic investment plan for 2015-2021, £0.6M were allocated for additional equipment to support Hull Physics research and project student training (including an Atomic Force Microscope, a CCD camera to augment the FLIM set-up capabilities, a High Precision Motion Control, and a new £110k fully automatic multi-turret e-beam/thermal evaporator). In parallel, the university invested in HPC with the installation of a new computational cluster in October 2016 (VIPER: composed of approximately 5,500 processing cores, at a total cost of £2.1 million). The Milne Centre obtained maximum benefit from these HPC investments with more than 50% of all the computational time available allocated for computational physics research. This facility also helped to train PhD students and accrued grant income worth three times its cost.

Our **laser science and nanotechnology research** is supported by a range of external sources encompassing UKRI, EU, industrial projects and charities. It has expanded rapidly over the REF period and its strategic plan is to directly engage in the “Health and Wellbeing” theme of the University through its research strength in nano-photonics, plasmonics, biophysics and health. In support of this area, significant university investment has provided new equipment (e-beam evaporator, fluorescence lifetime imaging microscope, X-ray diffractometer for scanning electron microscope, nuclear magnetic resonance instruments, capillary electrophoresis, atomic force microscope, glove box, matched funding for new laser equipment, totalling £1.1M), as well as completely refurbished lab space (£500k). The total Hull Physics lab space covers 1060m² and is shared between six experimental permanent academic staff (177 m² per permanent academic staff).

The lab space houses state of the art equipment including a spectroscopy and nanophotonics instrumentation suite; a nano-electronics characterisation laboratory, and laser experimentation space, all of which have strong interactions with industry as indicated below.

In addition, the experimental research groups also benefit from a shared clean-room with Engineering which houses Physics-owned key nanofabrication equipment including nano-imprint lithography and photo-lithography, and SEM.

This is complemented by a Faculty owned Microscopy Suite, which houses state-of-the-art equipment including:

- Zeiss EVO60 Scanning Electron Microscope with electron dispersive spectroscopy (EDS) and cryogenic capability
- JEOL 2010 High Resolution Transmission Electron Microscope with EDS capability and a Gatan Ultrascan 4000 camera for excellent image quality
- Zeiss Axio Vert.A1 inverted microscope and an Olympus IX 71 inverted microscope for wide field fluorescence microscopy
- Zeiss LSM710 Laser Scanning Confocal Microscope for laser scanning confocal microscopy
- Bruker Dimension Edge atomic force microscope, including conductive AFM modes

Further, it features a wet lab, an ISO standard 6 to 7 clean room containing all equipment necessary for the preparation of electron microscopy samples, an ultramicrotome, a cryostat and a critical point dryer for sample preparation. The Microscopy Suite is also open for work extensively with industry and other universities to assist with their analytical requirements.

The **Milne Centre** is co-located in 453 m² of office space within the main physics building. Our six permanent members of staff, three postdoctoral scholars, and 11 doctoral students occupy a suite of refurbished offices equipped with modern computing facilities. The Milne Centre is supported by external funding from STFC, RAS, EU, and Leverhulme to a total of approximately £1.6M over the REF period, as well as significant investment by the university in the form of PhD scholarships and computing.

The university is committed to support the Milne Centre as evidenced by its support for NuGRID, JINA, LSST, TAIPAN, and financial contribution to the Ogden Science Officer scheme (employing Urquhart during the period). The Centre aims to grow through diversifying its income streams, including interdisciplinary scholarship applications, and via intensifying outreach activities, for which it is already having a strong impact in the region and beyond.

4. Collaboration and contribution to the research base, economy and society

4.1 - Overview

In the REF period, Hull Physics has collaborated with over 100 other institutions (as evidenced by our published outputs), and with 43 other nations, including the Hull-led ThaiPASS partnership with Thailand funded by the STFC Newton Fund to enhance computation skills of school children. The University is also a partner on UKRI doctoral training provision (AURA EPSRC DTC, NERC Panorama DTP, China Scholarships Council, The Commonwealth Studentships Scheme) as well as our OfS funded WRIPA+ program.

Milne centre leadership and collaboration includes major roles in significant international projects with NuGrid - the nucleosynthesis grid collaboration (PI Pignatari); the joint institute for nuclear astrophysics (JINA international advisory committee Gibson; working group chair Pignatari); bridge research in the different disciplines related to the galactic chemical evolution and nuclear astrophysics (steering committee members Gibson and Pignatari); chemical elements as tracers of the evolution of the cosmos (ChETEC; WG leader Pignatari); the UK supercomputing consortium COSMOS executive committee Gibson); radial velocity experiment (RAVE building Gibson); GAs Stripping Phenomena in galaxies (Roediger); WiggleZ dark energy spectroscopic survey (PI and survey builder Pimbblet); galaxy and mass assembly (member Pimbblet); TAIPAN - a forthcoming survey of the Southern Sky (PI Pimbblet); large synoptic survey telescope (LSST board member Pimbblet); student exchange scheme with Budapest (Pignatari).

Gray Centre leadership and collaboration incorporates inception of the joint ultrashort laser material interaction facility at Hull, Luxinar Ltd. (Management board and PI Snelling); EU Horizon 2020 FET Open project POSEIDON (fabrication of on-chip light sources through self-assembly and electrically pumped quantum dots PI Buzzza; Bouillard; Adawi); UTT France student exchange scheme and facilities exchange (nanofabrication agreement; Bouillard, Adawi). Additionally, close interactions with the Energy and Environment Institute through a range of projects, including the Safeguarding our Waters PhD Cluster (Adawi, Bouillard, Kemp), and activities in the NERC Panorama DTP (Adawi, Bouillard), allows for direct applications of our nanoelectronics, nanophotonics, and nanomaterials research to key societal and environmental challenges.

Moreover as part of the EU project GEOSTICK, a joint PhD project (Benoit) on Astrobiology aims at modelling and measuring the attachment of life precursors (key molecules for the emergence

of life) on silicate clays: this is essential for understanding the stability of sediments on Earth, and gauging the possibility of life beyond our planet. In parallel, collaborations with the Hull-York Medical School (HYMS), NHS Castle Hill Hospital, and Staff at St Thomas Hospital (KCL) allow us to extend our impact to medical physics and biomedical sciences, for example with the design and development of multimodal 'theranostic' agents for thrombosis (Bouillard, MRC), the understanding and optimising of novel bioimaging probes (Adawi, Bouillard), or even artificial intelligence for cancer detection and treatments (Benoit, IOP and NHS).

Our **contribution to the research base** covers a wide array of items that include but are not limited to:

Journal editorship:

- Astrophysical Journal editor (Gibson);
- Publications of the Astronomical Society of Australia editorial board (Gibson 2014-2016);
- Publications of the Astronomical Society of Australia advisory board (Pimbblet 2014-2016);
- International Journal of Laser Science editorial board (Snelling and Walton);
- Frontiers in Astronomy and Space Science guest editor (Zharkov);
- International Journal of Wettability Science editorial board (Walton);
- Chemical Physics Impact editorial board (Benoit).

Learned Societies and Leadership:

- Council of the Royal Astronomical Society (Gibson 2016-2018)
- promoted to Fellow of the Astronomical Society of Australia in the period for recognition of professional achievements (Pimbblet)
- Members of the Institute of Physics (Bouillard, Buzza, Gibson, Snelling, Pimbblet)
- Fellows of the Royal Astronomical Society and International Astronomical Union (Benoit, Gibson, Pimbblet, Zharkov)
- Astronomical Society of Australia (Pimbblet)
- London Mathematical Society (Zharkov)
- Royal Society of Chemistry (Adawi, Benoit; Bouillard)
- American Astronomical Society (Gibson)

Additionally, Hull Physics staff have contributed to other leadership and advisory roles that directly contribute to the research base, the economy and wider society. For example, Gibson is one of the five members of the IOP Heads of Department (HoD) Steering Group, and in line with our equality, diversity and inclusion principles, he was also part of the IOP's Giving Voice to Inclusion Focus Groups, as part of its commitment to EDI. Additional highlights include the EPSRC Peer Review College (Buzza), membership of the board of trustees for the spacelink learning foundation (Gibson); advisory board of Yobi Minds Ltd. (Gibson); Royal Society University Research Fellowships panel (Gibson); Councillor on the governing body of the Royal Astronomical Society (Gibson); Rapporteur for the Italian Ministry of Education (Gibson); Management committee member of Molspin EU Cost action (Kemp); Institute of Physics Polymer Physics Group leadership committee (Buzza); Institute of Physics Liquids and Complex Fluids leadership committee (Buzza); board member for the Large Synoptic Survey Telescope (Pimbblet); and Project AURA (Snelling)

Conferences and conference leadership: Hull Physics staff gave approximately 60 invited talks and keynote addresses at national and international conferences. This incorporates leadership in SOC and LOC roles at a rate of 15%. We highlight, in particular, the STFC summer school (2016, held on campus; chaired by Gibson and run by the Milne Centre); the NAM - National Astronomy Meeting (2017, held on campus; chaired by Gibson and run by the Milne Centre - the first time either the Royal Astronomical Society or STFC conferences have operated on the campus of the University of Hull); Optical Wave and Waveguide Theory and Numerical Modelling, City University, London, 2015; Bouillard); HEIF-funded workshop on impact in outreach on campus (2018; chaired by Pimbblet, SOC and LOC including Bouillard); Royal Astronomical Society meeting on Quenching galaxies at high and low redshifts (2019; SOC and co-organizer Pimbblet); 5th Edition of the Nanotech France international conference and exhibition (2019; steering committee; Adawi). IAUS350 Laboratory Astrophysics – from Observations to Interpretation (2019; LOC Benoit).

Awards: Gibson was awarded the John Porter Memorial Lecture by the Institute of Physics in 2015, the Ray Bootland Memorial Lecture by the Hampshire Astronomical Group in 2019, and the Leon Davies Lecture by the Astronomical Society of Glasgow in 2019.

As a collective, the Milne Centre was awarded the Faculty's highest research honour for excellence in research (Faculty of Science and Engineering Research Excellence Award, 2017). This underscores its role as a key research jewel in the University, being responsible for a few per cent of the paper produced by the University, but accounting for almost ten per cent of all citations.

Further contributions to society: aligning with our anchor institution principles, our activities include the ThaiPASS Newton Fund's award to Pignatari to enable Python-programming education for students in Thailand, which is being exported locally within our schools network; teaching training and continual professional development; funding from HEIF to Pimbblet to explore the best ways to measure and quantify the impact of education and outreach research; and a STFC Spark Award (Pimbblet) to create 'escape rooms for outreach' based on STFC science and research.

Hull Physics is heavily involved in the University of Hull Science Festival, which runs yearly and is a prime platform to reach local communities and schools. We also contributed significantly to the British Science Festival 2018 (in Hull) delivering events around our key research (e.g. AI, Galactic evolution, Astro-biology). Finally, a number of our staff have held joint appointments with other institutes.

- Pignatari is a fellow of the Hungarian Academy of Science which has resulted in exchange students from both nations
- Pimbblet is an adjunct astrophysicist at the Monash Centre for Astrophysics, Melbourne, which has resulted in Australian graduate students making extended visits to the Milne Centre
- Bouillard is the University of Hull contact for the international Nano-Phot Graduate School (<https://nano-phot.utt.fr/partners>), which offers an unparalleled programme of excellence, with an international dimension and direct contact with scientific and socioeconomic stakes related to the use of light, on a nanometre scale and in a sustainable development approach. This advanced nanophotonics training sees research staff delivering an ambitious education program to train the next generation of researchers and professionals at the cutting edge of nanophotonic sciences and technologies.

Our KTP with Bemrose Booth Paragon Ltd (Snelling, Kemp), to develop new inks for a ticket printing company, was awarded “outstanding” for its final score. The partnership was shortlisted in the 2016 Knowledge Transfer/Exchange category of the Times Higher Education Leadership & Management Awards, and was commended highly in the 2016 Educate North Awards within the Commercial Engagement category. It won the 2018 Yorkshire Business Masters Investment Award and the 2017 Yorkshire Post Excellence in Business Turnaround Award. It was also shortlisted in the Innovation and International Trade category and the Advanced Manufacturer and Manufacturer of the Year category for the 2017 Yorkshire Business Masters competition and the 2017 Made in Yorkshire Awards, respectively. In May 2019, the award-winning partnership also claimed the Business Impact Award at Innovate UK's 2019 Best of the Best Awards.

Recently Hull Physics has started a project in collaboration with the local SME Qudos Energy which attracted 16k of ERDF funding (through the Aura Innovation Center) to develop new state of the art LED lighting solutions for the efficient growth of fruits and vegetables (Verrelli, Walton).

Further HEIF grants have supported Hull Physics' research, impacting:

- energy and environment (Hydrogen for Homes)
- neuromorphic computing (Ultra-fast Optical Switch Memristors)
- creating stronger ties with local education providers, local council authorities and stakeholders (workshop on impact in outreach on campus).

Hull Physics has won a large grant from the Office for Students to create work experience opportunities for physics students in local high-tech businesses. WRIPA+ (<http://wripa.ac.uk>) is an employability fund which has an appointed business engagement officer directly sourcing opportunities for our students. The business engagement officer will educate local high-tech businesses on what Physics students can offer, and then construct a database of internships for the students to access. The engagement officer (Ingham) also has a student facing role - offering personalised career support to Physics students. To maximise inclusivity and access to work experiences, WRIPA+ also funds travel and accommodation costs for placements in local businesses, tearing down any barriers stopping students from securing valuable internships.

In the near future, we will deepen our interaction with new start-ups in the artificial intelligence domain - chiefly Optalysis; a Wakefield based company growing new AI and machine learning methods that will directly enhance our research and feed into our curriculum via joint research projects. We are also starting new projects with the Energy and Environment Institute and the Natufia company to use nanophotonics to enhance their hydroponics product (Bouillard, Adawi).