

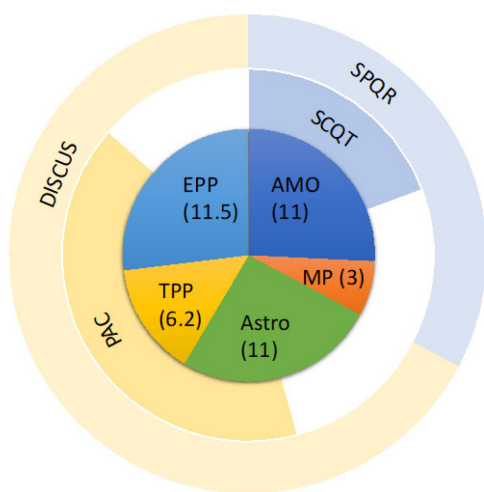
**Institution: University of Sussex**

**Unit of Assessment: UoA 9: Physics**

### 1. Unit context and structure, research and impact strategy

The Department of Physics and Astronomy (P&A) at University of Sussex (Sussex) prides itself as a highly collegiate and inclusive environment for exceptional research. We have a distinctive profile specialising in particle physics, novel quantum technologies and extragalactic astrophysics and cosmology. We nurture our researchers, especially our early career staff. Our main strategic priority is to enhance the impact of our research through substantial investment (>£16M) in academics, professional staff and infrastructure.

#### 1.1. Unit context and structure



*Figure 1* Schematic diagram of the 5 sub-disciplinary research groups within P&A. Research FTEs are indicated in parentheses. Interdisciplinary connections through research centres PAC, SCQT, SPQR and DISCUS are indicated.

P&A lies within the School of Mathematical and Physical Sciences (MPS), alongside the Department of Mathematics. P&A has 42.7 FTE independent research staff across five research groups:

- Astronomy (Astro, 11 FTE)
- Atomic, Molecular and Optical Physics (AMO, 11 FTE)
- Experimental Particle Physics (EPP, 11.5 FTE)
- Theoretical Particle Physics (TPP, 6.2 FTE)
- Materials Physics (MP, 3 FTE)

Since REF2014, P&A has appointed ten new Faculty: Krüger, Oručević, Weidt (AMO), Asquith, Shaw (EPP) and King, Boland, Dalton (MP) were recruited, while Byrnes (Astro) and Pasquazi (AMO) transitioned from proleptic positions. In addition, Gongora (AMO), Lindert (TPP) and Sutton (EPP) are Independent Research Fellows on open-ended or proleptic contracts.

Our department also leads four new interdisciplinary research clusters (see Section 1.4 for details) with most researchers belonging to at least one of these:

- Sussex Programme for Quantum Research (SPQR)
- Sussex Centre for Quantum Technology (SCQT)
- Data Intensive Science Centre (DISCUS)
- Particle Astrophysics and Cosmology Group (PAC)

The relationship between the groups and interdisciplinary centres is illustrated in Figure 1.

## 1.2. Strategy and Research Objectives

### 1.2.1. Development and monitoring of strategic plans

Recognising external drivers and group and individual strengths, our strategy is developed and refined both top-down and bottom-up. We implement Personal Research Plans in addition to Department, School and Institutional strategies. Coordination by the Research Strategy Group (RSG) includes heads of each group. An important innovation is the establishment of a board of External Research Advisors (ERAs Clare Burrage, Jon Butterworth, John Ellis, James Elliott, Gian-Luca Oppo, John Peacock and Christopher Sachrajda) to review our strategic plans. The ERAs enable focus on the most promising future directions (e.g. prioritising DUNE) and provide external input for institutional investments and support (Section 3.2).

### 1.2.2. Achievement of strategic objectives 2014-2020

Objectives defined in REF 2014 have all been realised. We aimed to expand our groups, pursue high-quality research, and drive new experimental activity with the specific intention of increasing our socio-economic impact. Through targeted recruitment, groups are now at sufficient size (Section 1.1) to undertake world-leading research (Section 1.2.3). As planned, we established a new Material Physics group. Our expanded research capacity is sustainable, as evidenced through diversification and increase in research income (Section 3.3).

Following REF 2014, our key priorities were diversification of income, generation of impact and increased professional support - this pre-empted the UK industrial strategy and UKRI priorities. We achieved our aims through:

- Strategic hires
- Matched-funding
- Expanded and enhanced laboratory space
- Increased professional support (especially for business development)
- Interdisciplinary and external engagement support structures
- Institutional funding for PhD students

The support includes over £16M of direct investment (Section 3.2).

P&A continues to be an active member of the South-East Physics Network (SEPNet), focussing on graduate training through GradNet, the doctoral training element of SEPnet (Sections 2.2, 4.6), advancing equality and diversity (Section 2.3), and facilitating enhanced engagement with the regional economy (Section 4.2). This directly benefits Sussex research through DISCnet and increased TPP income.

## 1.2.3. Research Quality

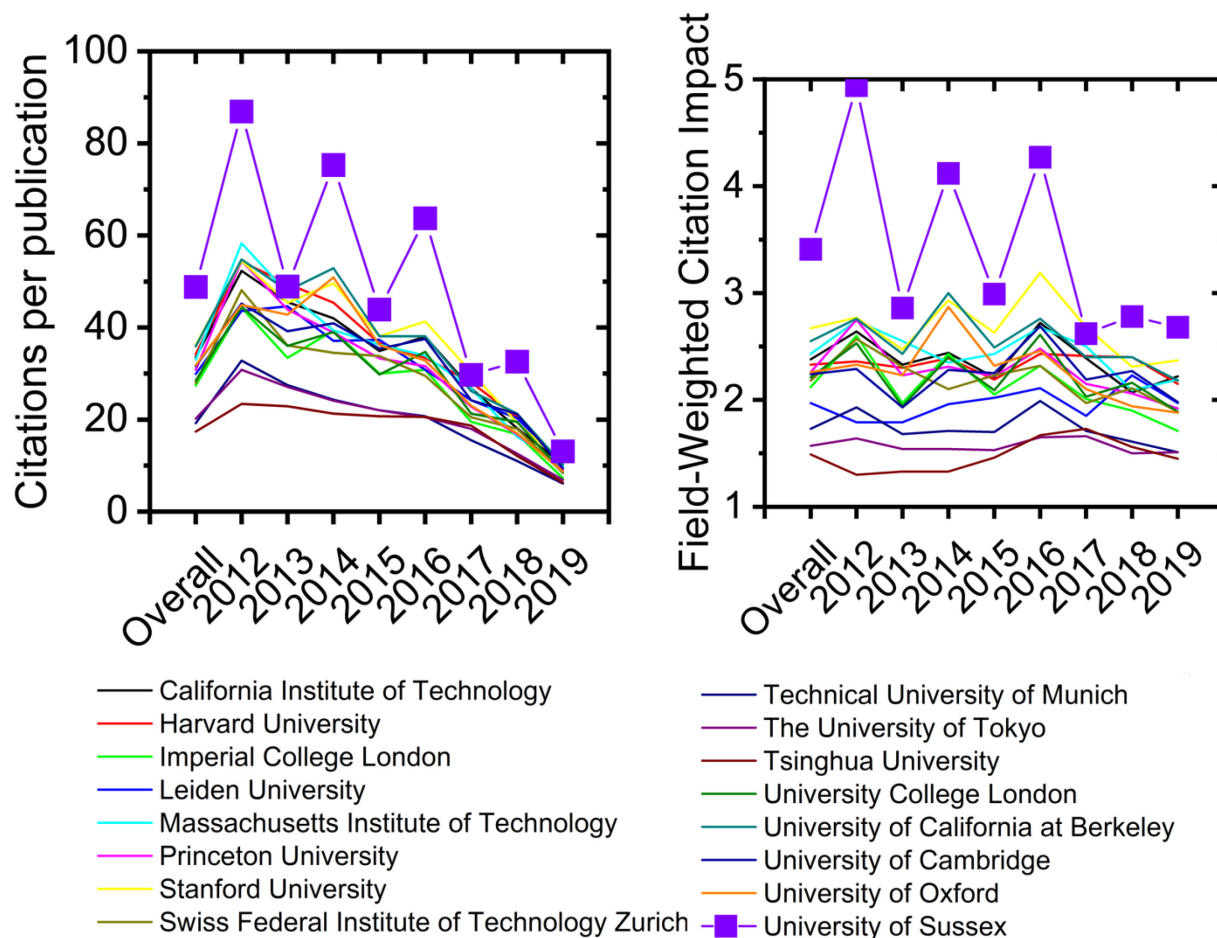


Figure 2 Citation metrics in P&A at University of Sussex for 2012-2019 in comparison to major institutions. Left: Citations per publication. Right: Field-weighted citation impact. From SciVal 6th Nov 2020.

Our research quality, measured in Citations per Publication, exceeds those of major universities in every year 2012-2019 (SciVal, Figure 2); we also exceed those institutions in Field-Weighted Citation Impact (Figure 2, right). This quality is internationally recognised: Sussex featured as a rising star in the [Nature 2016 Index of the global 500](#) "...mainly thanks to quadrupling of physical science score".

## 1.2.4. Objectives 2021-2025

We strive to enhance our reputation as an outstanding department producing world-leading research in our specialist areas. We aim to be innovators in multidisciplinary research, creating major academic and socio-economic impact. Our specific departmental targets for 2021-2025 are:

- Strategic growth to double our FTE in MP
- Targeted recruitment of the best talent through prestigious fellowships backed by proleptic lectureships (Section 2.1)
- Continue generating high quality outputs, matching the best universities in the world (Figure 2)
- Increase income and reduce risk through further diversification (Section 3.3) and SMART optimisation of application and success rates
- Enhance economic impact by strengthening our strategic partnerships (Section 4)
- Ensure the wellbeing, and effectiveness, of our staff, with a new Faculty role overseeing fixed-term staff (projected: March 2021) and early compliance with the UUK Concordat to Support Career Development of Researchers (Section 2)

- Create a diverse research workforce through our equality, diversity and inclusion policies (Section 2.3)
- Each research group has a clear focus, ensuring critical mass and research and impact outcomes of exceptional quality (Section 1.2.3).

### Astro

Astro focusses on cosmology and galaxy evolution, with broad theoretical, numerical and observational expertise.

Our strategy to lead large survey projects including Planck, Herschel, and the Dark Energy Survey (DES), has been successful, attracting funding from the EU and STFC (Section 3.3). Academic impact has been enhanced through the continued development of essential tools for the community, e.g. [CAMB](#), and [COSMO-MC](#) and our impact strategy is dissemination through data science with DISCUS and public engagement (Sections 1.3, 4.2, 4.3, ICS#3).

#### Future objectives:

- Exploit our investment in new survey facilities (Section 3.2) and our leadership roles in upcoming projects e.g. 4-MOST (Section 4.1)
- Enhance our efforts to realise the benefits of data science for UK skills and economy

### AMO

AMO focus on developing quantum technologies and their foundations and applications. We are one of the largest ion trapping centres worldwide, with more than ten operational systems.

We have influenced public policy (ICS#2), invested heavily in our strengths (Section 3.2) and enhanced collaborations nationally and globally. We gained central roles in the UK National Quantum Technologies and the European Quantum Technology Flagship programmes (Section 3.3), secured EPSRC Quantum Technology Fellowships and won two major EU-ERC quantum technology grants.

Our impact strategy is to influence global policy, encourage public engagement and enable technology transfer (Sections 1.3, 4.2, 4.3, ICS#2, ICS#4).

#### Future objectives:

- Grow technology transfer
- Increase the number of industry-led projects
- Maximise benefits from collaboration with e.g. National Quantum Computing Centre
- Accelerate application of quantum technologies in other research domains

### EPP

EPP explores the frontiers where new physics might be found, with a strong focus on collider and neutrino physics (Section 4.1).

Our strategy is to lead the exploitation of existing experiments, evidenced by major contributions to a large number of high-impact papers. We have influenced international direction through European Strategy for Particle Physics and secured leading roles in the preparation of future high-profile experiments. Our technical contributions showcase our expertise in data science, scintillator technology and high-speed FPGA-based data acquisition systems.

EPP's route to impact has three pathways: public engagement, applications of detector technology, and data science through DISCUS (Sections 1.4, 4.2).

#### Future objectives:

- Enhance our influence in the decision-making process for the future collider programme
- Consolidate our key roles in preparations for upcoming experiments, ensuring continued leadership in the exploitation of high-profile projects

**TPP**

TPP covers four main areas: particle astrophysics and cosmology; particle phenomenology; tools for high-energy physics; quantum field theory and quantum gravity.

Our research has direct impact on experimental searches, including experiments at CERN; dark matter searches; and gravitational wave observatories. We nurture strong international partnerships. We formed SEPTA with RHUL and UCL, growing our STFC consolidated grant by 40%, and gave strong support to the NExT regional consortium. We secured new funding to provide key theory expertise for QSNET and QUEST-DMC in STFC's QTFP programme.

Our impact strategy focuses on interdisciplinary research mediated through DISCUS.

**Future objectives:**

- Maximise and strengthen our core expertise to provide world-leading tools in LHC searches
- Exploit and guide new physics searches in particle phenomenology, particle astrophysics, and cosmology
- Realise the opportunities of the QTFP programme

**MP**

MP has made major, innovative contributions in the field of low-dimensional nanostructured materials, e.g. a method for spinning continuous nanotube fibres having record lengths, tensile strengths, and toughness. Our emphasis is on applications of these materials from bio-scaffolds to sensors and robotics.

Three well-equipped laboratories were established as part of our strategic investment (see Section 3.2), leading to rapid success and over £3M in funding since 2016 (Section 3.3).

Our impact strategy focusses on the transfer of solution-processed nanomaterial technologies into global markets transfer, especially in collaboration with spin-out company [Advanced Materials Development](#) (Section 4.2, ICS#1).

**Future objectives:**

- Izabela Jurewicz, a UKRI Future Leaders Fellow, joins us in November 2020 as Faculty and we will prioritise support for her to establish her programme
- Use SPQR as a networking and promotion vehicle to strengthen the key research theme of biomaterials/biophysics

**1.3. Facilitating Impact**

Since the last REF period, P&A has undergone a culture change with a steadily increasing portfolio of research focussed on impact. It has engineered impact facilitation through strategic recruitment of academics whose research and expertise has technology transfer (Krüger, Dalton), or engagement potential (Shaw), and invested in infrastructure to support this.

**1.3.1. Public Engagement**

Our engagement activity has been strategically refocussed to engage larger audiences with our research and is strengthened, particularly internationally, with new Faculty roles of Research Communication Officer (Shaw) and Public Engagement Director (Wilkins), successes include two STFC public engagement fellowships and over £250k of STFC awards.

One exemplar of our engagement work is the ATLAS Open Data Project, led by Shaw, which provides publicly accessible collision data and simulations from the ATLAS experiment. This is used globally by undergraduate students, secondary school students and the public to develop programming and analysis skills, alongside an appreciation of the scientific method. We plan to apply this model to future high-impact particle physics experiments, in particular DUNE.

Our strategic approach is exemplified by our work raising awareness of quantum computing, leveraging our unique “blueprint” for a quantum computer. We have engaged audiences of



millions, most spectacularly via an award-winning walk-in installation in London's Financial District. This has encouraged substantial investment in quantum computing (ICS#4).

For other examples, see: Section 4.3.

### 1.3.2. Technology Transfer

P&A has developed a five-year plan, based on clear pathways to impact through strategic initiatives, long-term industrial alliances with partners in key sectors, and a strong regional presence. P&A has worked closely with the University's central Research and Enterprise team to ensure alignment with wider institutional direction.

Key impact areas have been identified as quantum technologies and materials, and data science. Future impact in these areas will be enhanced through the SPQR "Sussex Quantum Partners" industrial liaison programme and DISCUS. Focussing external engagement on key sectors will create buildable impact and strong reputation, in turn attracting further partners to create a self-sustaining research community.

Dedicated Professional Services staff have been recruited, including a full-time STFC Innovations Partnership Scheme Fellow (IPS Fellow) in 2014; a position which has subsequently been made permanent (Section 3.5). Resources include the STFC Impact Acceleration (IAA, Section 3.7). The IPS Fellow has been instrumental in developing and securing partnerships and promoting engagement through local data science industry networking initiatives (Section 4.2). Projects funded through IAA have secured approximately £2.96M in further grants to date. Entrepreneurship training and mentoring by the IPS Fellow has transformed enterprise culture and led to e.g. the formation of [DataJavelin](#) (a data science consultancy) by two Sussex Fellows (Section 2.1.2).

An additional business engagement officer was recruited in 2019 for SPQR and is now leading the development of Sussex Quantum Partners, a key success being a £5.5M Innovate UK grant with the second largest UK battery factory (AMTE Thurso).

### 1.3.3. Impact Case Studies

The four selected Impact Case Studies arise directly from our impact strategy:

- **ICS#1 "Commercial Exploitation of Nanoparticle Based Inks ..."** — arises directly from our appointment of Dalton and the spin-out of AMD
- **ICS#2 "The impact of quantum computing research on the adoption of public policy"** — arises from the strategic planning of SCQT
- **ICS#3 "Satellite data processing ... enabled better forecasting for improved drought resilience in Africa ..."** — arises from a collaboration initiated and supported by DISCUS.
- **ICS#4 "... commercial investment towards the development of a practical quantum computer"** — arises from the strategic planning of SCQT and the spin-out of Universal Quantum

### 1.4. Interdisciplinary research

To achieve our research objectives, broaden our income streams and engage with the UK industrial strategy and UKRI impact agenda, we have radically advanced our approach to interdisciplinary research. We have founded three University-recognized interdisciplinary research clusters: SPQR; SCQT and DISCUS, all supported by substantial investments in direct start-up costs, in-kind support of research bids, and studentships and on-going income sharing schemes (see Section 3.2). These clusters have attracted considerable success e.g. the award of significant funding through the Quantum Technology Hubs, the award of an STFC Centre for Doctoral Training (DISCnet) (see Sections 3.1 and 3.3), three interdisciplinary Outputs (submitted to UoAs 9, 4 and 14) and ICS#3. The interdisciplinary PAC has enabled one successful application to STFC Ernest Rutherford Fellowships (Figueroa), while emerging research collaboration with Mathematics is facilitated through the Mathematical Physics group.

### 1.5. Open Science

P&A has a strong commitment to Open Science e.g. the ATLAS Open Data Project (Section 1.3.1).

A second example is the Sussex-led €2.5M European-funded Herschel Extragalactic Legacy Project (HELP), which has collected a vast quantity of data from surveys by major international observatories. Value has been added through new software tools and derived data, accessible via Virtual Observatory compliant servers at Sussex, while software is shared through GitHub.

P&A is also strongly committed to open publishing - the Open Journal of Astrophysics was founded by Peter Coles while at Sussex and nearly all articles are shared through ArXiv. From August 2011, Sussex mandated depositing all peer-reviewed research outputs and associated metadata. Our preference is to use a Green Open Access route for publication and if unavailable, the Gold Open Access route is used. For UKRI-funded research, a block grant is available to support Gold.

### 1.6. Research Integrity

Sussex is committed to promoting and upholding the highest quality academic and ethical standards and endorses the UUK Concordat to Support Research Integrity. The University has developed robust [research governance and ethics policies and procedures](#) that recognise the importance of addressing ethical matters. These procedures and policies underpin all research at the University and are publicly available on the University website along with the [Code of Practice for Research](#). Sussex has a register of interests to avoid conflicts of interest, and detailed policies on the management of research data and information security.

Most importantly, research integrity and ethical standards are upheld by the culture that is embedded in P&A. All new staff are mentored and guided in the importance and conduct of open, transparent and collaborative research, as articulated in the [School Vision](#).

## 2. People

### 2.1. Staffing Strategy and staff development

#### 2.1.1. Strategic Staffing and Recruitment Strategy

Our staffing strategy covers our Teaching and Research staff (Faculty), our post-doctoral, research-only staff (Fellows) and our technical and professional staff. It has three main themes:

- Expand quantum technology and material physics through the interdisciplinary programme at their interface: SPQR (see Section 1). To achieve this, we recruited research leaders of international standing (Krüger and Dalton), supported with Lecturers (Oručević, King, Boland)
- Recruit staff with skills specific and essential to our impact strategy. Skills gaps were filled by professional business development staff (Section 3.4) and targeted recruitment of Faculty with a unique public engagement profile (Shaw)
- Enhance our research capacity and facilitate on-going strength and succession planning through expanded recruitment, and subsequent development of, exceptional early career researchers (Fellows and PGR)

Seb Weidt joined P&A in 2005 on BSc Physics with Management studies. He undertook a PhD (2010-2014) in Quantum Information Technology supervised by Hensinger, receiving essential research training. He continued as Research Fellow (2014) taking on more responsibility for commercialisation and public engagement and was promoted to Senior Research Fellow (2015) and Lecturer in 2018. In 2019 he co-founded Universal Quantum with Hensinger and now has a joint appointment as CEO (see ICS#4).

*Box 1: Case Study of staff development. Weidt was one of 5 staff (3 female) who joined Faculty from Fellowships.*

Since 2014, P&A recruited eight new Faculty (Krüger, Boland, Dalton, Oručević, Shaw (direct appointments) and Asquith, King, Weidt (via Fellowships). Two Fellows on proleptic Fellowships have transitioned to Faculty (Byrnes and Pasquazi) (Section 1.1). We recruited a further independent Fellow who is on a proleptic position (Lindert) and have two Fellows who have achieved independence (Gongora, Sutton). Professional Services staff provision expanded from 1.3 to 7.5 FTE (Section 3.5). Our strategy both required and facilitated a 55% increase in the number of research-only staff since 2013/14, from 28.5 FTE to average 44.0, with a rise in Fellow/Faculty from 1.4 to average 2.4 (Figure 3).

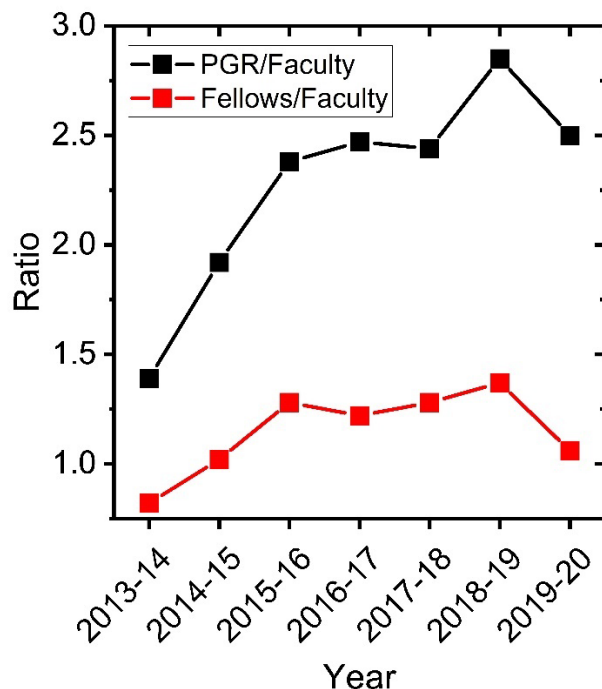


Figure 3: Researcher FTE per Faculty FTE since 2013/14 – PGR (black) and Fellows (red).

### 2.1.2. Staff Development

The University Research Staff Working Group, led by an academic Director, oversees all areas of research staff support. Sussex has held the HR Excellence in Research Award for the past six years by following the principles of the UK Concordat to Support the Career Development of Researchers.

Researcher development in P&A is led by the Director of Research and Knowledge Exchange, working with Professors from each research group and we are developing a new Faculty role to focus on the career development of our Fellows (to be in place by March 2021). We already follow the principles of the 2019 Concordat closely.

Our staff development, beyond the usual training offered centrally, nurtures early career researchers through a strong collegiate spirit and peer mentoring. New Fellows and Faculty are strongly supported within their research groups and are additionally assigned a mentor, often from outside their group. New Faculty are established with significant financial investment (Section 3.2) and all have reduced teaching and administrative duties.

Research enhancement for Faculty is enabled through sabbaticals (one semester every four-and-a-half years), plus long-term research leave (e.g. by Sanz) to develop and grow new areas of excellence. Senior staff receive significant support to develop impactful research with e.g. a five-year Research Professorship for Krüger. Opportunities for leadership experience are identified and encouraged, with Readers often representing research groups on the RSG.

We devolve funds to progress research and provide opportunities for pump-priming (Section 3.2). We provide pre-submission and post-outcome grant review to generate and integrate feedback. We employ external companies to support strategic grant applications e.g. the



successful ERC Consolidator award to Peccianti (2016). This also equipped our staff with skills to run mock interviews, resulting in further success e.g. ERC Starting Grant for Pasquazi (2019).

The career progression of Faculty from 2014-2020 exhibits a steady promotion through Lecturer, Senior Lecturer/Reader, to Professor – with 20 promotions to the role of Professor since 2014. Two Professors have also been promoted to Senior Management positions: Harris, to Head of School (2014) and Oliver, to Deputy Pro-Vice-Chancellor Research (2020).

We have lost just seven Faculty over the same period. Of those, two transferred to research-only positions and three had been employed on fixed-term contracts (one of these was re-employed as our Technical Services Manager, the others took up academic posts elsewhere). Coles, our former Head of School, returned to a post in Cardiff and Eberlein joined Loughborough as Dean of Science.

P&A has refined the University appraisal process to more accurately reflect each career stage for Fellows. Line managers explicitly review and consider each of their research staff for promotion annually and the progression of Fellows has thus been a particular success in recent years. Five research fellows have joined Faculty through direct appointment or via proleptic positions (e.g. see Box 1). In 2014, all Fellows were Grade 7, except a retiring Faculty member (Grade 9) and one Royal Society URF (Grade 8). The REF period has seen seven promotions to Senior Research Fellow (Grade 8) and in 2020; we have seven Fellows at Grade 8 and one Grade 9. Six of our Fellows hold open-ended contracts.

We work intently to grow academic careers and 102 staff have transitioned out of research-only roles since REF2014. The first destination for ten such staff was a Faculty position (six at Sussex including one in the Department of Informatics), while at least two others have subsequently secured Faculty positions. Ten are independent Fellows. In total, 64% succeeded to academic jobs. All destinations are indicated in Figure 4.

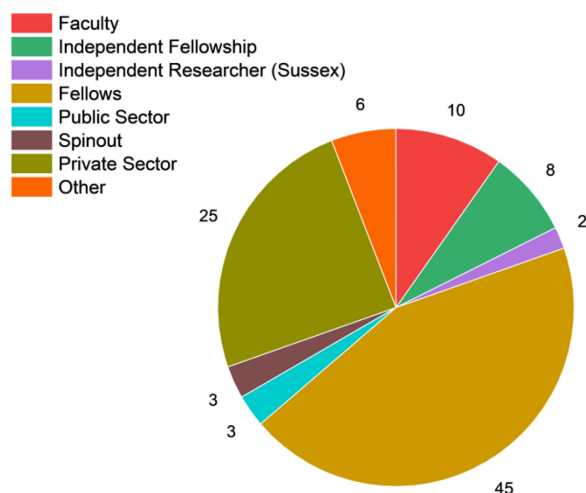


Figure 4: First destinations of 102 research-only staff since 2014.

Consistent with our impact strategy (Sections 1.3), we value enterprise highly. We encourage exchanges with industry for all researchers. Examples include Dalton, who is seconded to AMD one day per week, Weidt and Hensinger, with 50% of their time allocated to [Universal Quantum](#) and Abel, a Fellow, seconded to [cdo<sup>2</sup>](#) for 6 months. We enable early career researchers to develop the commercial potential of their work and have facilitated two Enterprise Fellowships from the Royal Society of Edinburgh for former PhD students: Waterfield progressed to develop the spin-out Pulsar Optics and Baruah to develop his company Viridian Logic (winners of the Product, Service or Technology Award at the Sustainability Impact Awards 2020). Through DISCUS, we also supported PhD student Shehu to develop the spin-out [Calypsort](#) (this led to him being recruited as Research Scientist for [Moogsoft](#)) and Fellows (and former PhD students) Hurley and Rooney to co-found [DataJavelin](#), a machine-learning consultancy.

## 2.2. Research students

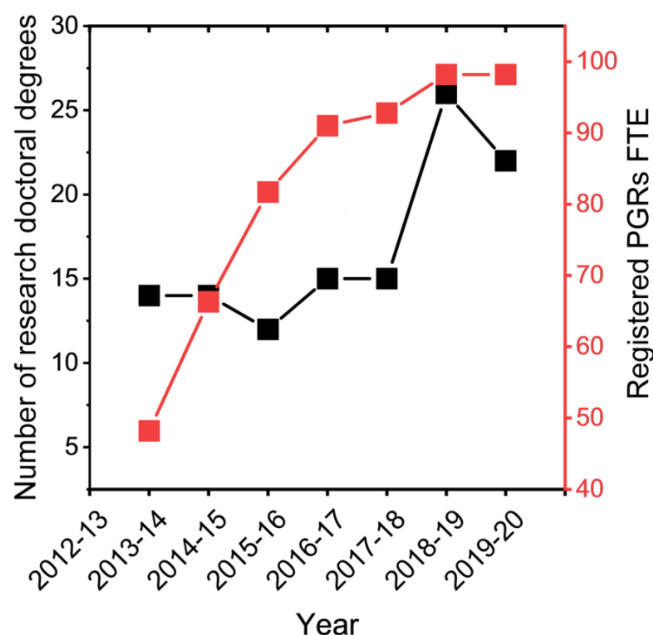


Figure 5: Number of PhD degree awards in Physics and Astronomy by year since 2008/09 (black) and number of PGR FTEs (red) since 2013-14.

Our doctoral research students (PGR) are significant contributors to our research environment and to the health and sustainability of the discipline. Doctoral research is central to our research strategy, underpinned by substantial investment and strong support structures. Over the REF period, the department has seen 115 PhD awards, while student/supervisor ratio has risen from 1.4 to 2.5 (Figure 3). Of 107 REF outputs, 60 have PGR authors and 43% of our PhD graduates progressed to Fellowship positions as their first destinations. Our student body is internationally diverse, drawn from over 30 countries, with 31.6% of our 1220 applicants joining us from outside the EU. Year on year, around 25% of our PGR cohort are female.

PGR studentships rose from 41 FTE in 2013/14 to 96 FTE in 2019/20, thanks to substantial University investment, which supported 48 students (including through the University's Chancellor's International Student Awards). This complements a wide range of external funding (as at 1 October 2019):

- 40 UKRI
- 5 DSTL
- 3 EU
- 1 Private sector
- 1 SEPnet
- 2 Royal Society
- 1 China Scholarship Council
- 1 ITN student

We co-lead the data-intensive science centre (DISCnet) CDT and host students from several other CDTs. GRADnet provides enhanced training and employer engagement opportunities (Section 4.6).

All our students are supported from recruitment to first destination by processes and arrangements managed by the University's Doctoral School, the Research Degree Committee and the School Director of Doctoral Studies (DDS), who is a member of SMT and the University's Doctoral Studies Committee. Our arrangements are accredited by STFC - SEPnet's employability programme is cited by STFC as good practice. As a result, all 106 thesis submissions over the REF period were on time, we have had a modest number of twenty withdrawals, most of them for health reasons, and no fails.

Students are selected through open recruitment including interviews, carried out by research groups, overseen by the DDS.

Students are embedded in research groups and are assigned at least two supervisors. All faculty undergo unconscious bias training, supervisors are offered initial as well as refresher training, and fulfil a training module on mental health and well-being of research students. Supervision arrangements and progress are reviewed annually, allowing problems to be addressed early. This includes assessment and feedback by independent Faculty based on a written report and interview, with interim reviews and deliverables scheduled if needed.

Students tailor, document, and review their own training programme annually through the University's Training Needs Analysis process. Typically, students take 100 hours of discipline-specific training, chosen from a diverse offering of advanced courses. All students are required to give talks on their research and are expected to attend internal seminar series and international conferences. This training programme is diversified through long-term attachments (LTA) and through research and transferable skills training including presenting, scientific writing, and entrepreneurship offered by the Doctoral school and GRADnet or comparable professional skills training. DISCnet provides intensive additional training in data science to its students, which includes twenty days' residential training during the first year and is available to non-DISCnet students. Both MPS and GRADnet run student-led conferences each year.

Student well-being is a key concern and students have recourse to the DDS and the Director of Student Experience. It is a focus area of the annual review. Students have access to a team of dedicated advisors and counsellors in the Student Life Centre. Disability support is provided by the Student Support Unit. Support for PGR mental health and well-being has been improved through a HEFCE Catalyst project over the REF period, including new dedicated supervisor training.

### **Outcomes and Career Destinations**

The perfect on-time submission record over the REF period is accompanied by a large number of journal outputs, including around 60% of our REF outputs. Research successes are celebrated, including through annual prizes at University and School level and one dissertation recently won a Springer Thesis Prize. The University's careers service provides one-to-one advice, career exploration workshops, CV writing and interview workshops, employer events and alumni fairs. Career planning is integrated into the annual review process.

Training to support entrepreneurship and commercial activity is provided by the Doctoral School, via GRADnet, and has been run or arranged by the IPS Fellow, offering sessions on intellectual property, start-ups and software licencing. This industry focus is supported by the SEPnet-run eight-week industry placement scheme and the DISCnet integrated research placement in non-University environments, offering six months' workplace experience.

Of our graduates, 43% go on to a Fellowship, 11% to data science roles in the private sector, 5% into government, 5% onto teaching roles in secondary or tertiary education, 18% into other private sector roles, with the remainder unknown.

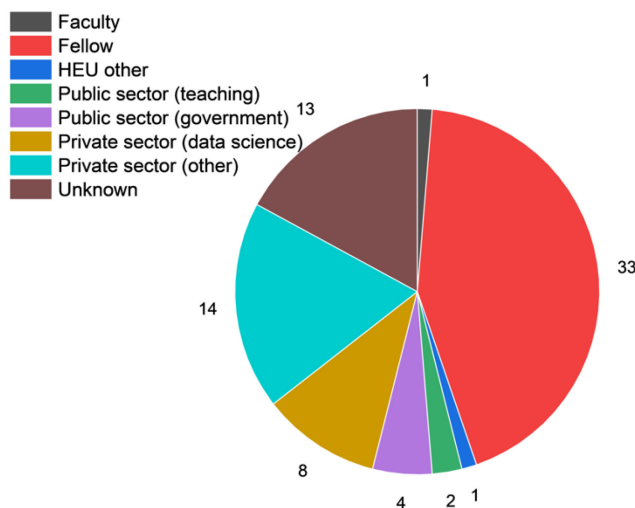


Figure 6: Distribution (%) of PGR first destinations based on a sample of 88 students completing between 2014 and 2020

### 2.3. Equality, Diversity and Inclusion

Equality, Diversity and Inclusion (EDI) is fundamental to the P&A culture and articulated in our seven-point [Guiding Principles](#). Our EDI strategy builds on a strong University commitment, exemplified by the appointment of a Deputy Pro-Vice-Chancellor for Equalities and Diversity (2017), the establishment of an EDI unit and the introduction of a new institutional EDI Strategy (2017). The School of Mathematical and Physical Sciences holds an Athena SWAN bronze award and EDI is overseen by the Director of Equality and Diversity.

P&A strategy seeks to recruit, support and retain the highest-quality researchers from all ethnicities, genders, sexualities, disabilities, ages and beliefs. We have a diverse Faculty from thirteen countries with a gender ratio of 20% – an increase from 14% in 2014. The gender ratio for those joining Faculty is 4/10 (40%) and 3/5 (60%) for those transitioning to Faculty from Fellowships. We also have three female Professors, up from one, and another (Eberlein) moved to senior management at Loughborough.

We recognise that much more needs to be done and are working with the University and SEPnet to increase diversity at all levels. Our strategy focusses on three aspects: **showcasing diversity** to encourage students and early career researchers from all backgrounds into research; **recruitment** of staff from a diverse pool; and enhancing an **inclusive, supportive and transparent culture** to attract and retain outstanding researchers.

#### Showcasing Diversity

- Female Head of Department from 2015 to 2017 and 3 female P&A members of School executive
- Throughout this REF period, at least one of our research group leaders has been female
- Staff with protected characteristics are strongly represented on committees and in senior administrative roles with a gender ratio of 40% in committee chairs (balanced by reduction in other duties)
- Our outreach and public engagement activities employ students and staff from diverse backgrounds. In 2018-19, 51% of the students involved were female and 19% BAME, significantly higher than our student population

#### Recruitment

All recruitment panels for research staff and PGR must:

- Have up-to-date training in recruitment policy, unconscious bias, and EDI

- Include at least one female member

#### **Inclusive, supportive and transparent culture**

- Official meetings are held 10am-4pm. Sending emails outside normal working hours is strongly discouraged
- Carers have reserved parking
- Flexible working policy. Examples include supporting Sanz in taking long-term leave for family reasons and to explore new research directions; King and Sargent with extended parental leave, and Hindmarsh with part-time working to facilitate his collaboration with the University of Helsinki
- Strong support in anticipation of, and following, career breaks (see Box 2)
- Dedicated EDI and well-being champions provide confidential points of contact
- Working closely with Occupational Health to fully support staff with disabilities, included reducing a staff member's workload by 20% (while remaining 1.0 FTE), working with the Timetable team to adjust schedules
- A detailed and transparent workload model and regular check for biases. The model includes all EDI related activities
- Committee minutes are openly published
- A bookable, wellbeing space for e.g. informal discussion, breastfeeding or relaxation
- Funding provided to support carers for research travel
- Quantity of travel is not considered when assessing promotion
- Staff are encouraged to display their pronouns and many wear LGBT+ supporter badges
- Regular events to celebrate diversity such as LGBT+ STEM Days, '*Black Lives Matter*' discussion events and International Women's Day events

To achieve a fair and transparent process for REF we have ensured that:

- Preparations followed the institutional Code of Conduct, agreed after extensive consultation
- P&A procedures for selecting Outputs were published to all staff. Authors provided a grade estimate which Heads of research groups used to guide them in selecting those for grading by our ERAs
- Eligible researchers were regularly informed about their Output selection and grades

An analysis of submitted Outputs showed that three or more were submitted from 43% of female researchers, compared with 30% from male researchers, indicating no gender bias against female staff in the Output selection process. There were no significant differences on the basis of ethnicity or disability and there was no bias against younger staff.

Our EDI strategy aims to increase the number of applications from under-represented groups at all levels and to increase the number of female Professors to five by 2025. We will also run and publish annual surveys to understand and accelerate our progress on EDI.

### **3. Income, infrastructure and facilities**

#### **3.1. Research Funding Strategies**

Our key aims during the REF period were to increase funding and diversify its sources. Our funding increased steadily from £2.1M in 2008/09 to £3.3M in 2013/14 but was highly concentrated, with 54% from STFC and 20% from EU (Figure 7). In 2016, the department therefore established two new professorial positions in materials physics and quantum sensing, with a particular emphasis on developing new industrially-focussed funding pathways, aligned with UKRI priorities. Both included substantial start-up funding and extensive newly-refurbished laboratory space. The two appointees, Dalton and Krüger, established SPQR as a vehicle for interdisciplinary collaboration and forging links to industry partners. We also invested heavily in PhD students and professional services staff.



**3.2. Institutional Investment**

We have been extremely successful in securing institutional investment into P&A, particularly through the University's Strategic Development Fund (SDF). In REF2014, we reported £10M SDF investment. Since then, we've benefited from an additional £11.16M of direct SDF investment (29% of the institutional total), of which £9.15M has realised our key strategic priorities of establishing materials physics and expanding quantum technologies, as discussed in Section 1.2.

SDF investment has also leveraged substantial additional investment from the School. In total, £8M was invested in the establishment of Krüger's research programme (including £2.4M for laboratory refurbishment), £2.3M for Dalton's (including substantial laboratory space and equipment: see Section 3.5) and £1.7M in matched-funded support of the Quantum Technology Hub bids. Additional laboratory refurbishments (Section 3.5) have cost £0.46M.

The School has provided £2.74M for technical staff (above that included in SDF) and £0.40M for research staff.

Devolved Budgets give academics autonomy to invest in and direct their research. These budgets are used to incentivise grant applications, as income to Devolved Budgets is 4% of Contribution Income awarded with a minimum of £1k/yr. Devolved Budgets received £69k in 2019/20 and the total spend has been £585k since 2014.

Significant additional investment comes via the Doctoral School, which matches funding for doctoral students from UKRI schemes. Since 2014, we have provided funding of £3.5M for PGR.

The University stimulates new research through the Sussex Research programme, which runs a number of funding schemes at different scales:

- P&A were awarded £71k from the Research Development Fund, resulting in grant applications totalling £9.8M and awards totalling £2.1M
- Research Opportunity Funding of £2.3k supported the engagement leading to Quantum Technology Hub awards (£2.6M)
- A Thematic Programme Award (GCRF-DISCUS) of £10k (leading to e.g. the STFC-GCRF funded £115k AstroCast project and ICS#3)
- The Kroto Fellowship award to King and the Helena Normanton Fellowship to Gongora (£40k)
- International Studentship Programme awards (£3.5k) and Briggs Fellowship funding of £16.6k to support Fellows visiting Romer and Wilkins

Sussex also invested in subscriptions or buy-in to international facilities e.g. membership of the 4-metre Multi-Object Spectroscopic Telescope consortium (4MOST, €400k) and approximately £90k to join the East Asian Observatory collaboration to access JCMT.

The total investment in P&A is accounted for through the Transparent Approach to Costing (TRAC) system which audits the Full Economic Cost of research and the external revenue. Data is available from 2016/17 and, in the four financial years until 2019/20, the net investment from Sussex into P&A research was £16.4M, i.e. £4.1M/yr.

### 3.3. Research Funding Outcomes

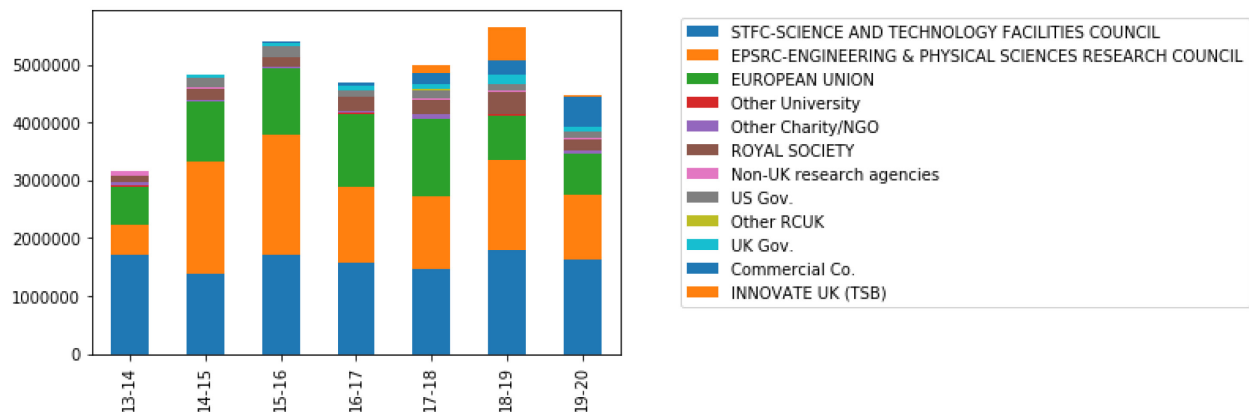


Figure 7: Annual research grant income by year 2013-2020, broken down by funder.

Our research strategy has been rewarded with £34.4M of new awards (2014-2020). £20M of this comes from large awards (over £840k). The strategic investment in quantum technology resulted in £7.4M over seven EPSRC Quantum Technology Hub awards and a further £5.9M in other quantum technology and related awards. The MP group has had rapid success with awards of £3M, including £1.6M funding from AMD (Section 4.2). The core funding for Astro, EPP and TPP has continued to build with consolidated grant awards of £2.2M, £4.2M, and £2.0M respectively.

Research support (Section 3.5) enabled us to pursue highly competitive international awards with e.g. two ERC consolidator Grants (Peccianti and Lewis) and three ERC starting grants (Hartnell, Pasquazi and Seery).

Our strategy of supporting competitive prestigious fellowships has also achieved considerable success:

- Two EPSRC Quantum Technology Fellowships (Pasquazi, Verdu - AMO)
- Royal Society University Research Fellowship (Fialkov - Astro) and extension (Byrnes - Astro), Royal Society Dorothy Hodgkin Fellowship (Asquith - EPP)
- STFC Ernest Rutherford Fellowship (Lindert - TPP)
- Marie Skłodowska-Curie European Fellowship (Tamsett - EPP)

We additionally obtained £2.2M funding to support our roles in international projects and collaborations e.g. £0.47M for ATLAS upgrade and £0.95M to support our role in DUNE.

£1.1M was awarded to support commercialisation and impact generation in STFC areas, including two GCRF projects and two Royal Society of Edinburgh Enterprise Fellowships. We have also raised £250k to support STFC related public engagement.

Overall, since 2014/15, grant income averages at £5M p.a. (see Figure 5). The rise since 2013/14 is primarily through an increase in income per Faculty FTE; income was £88k/FTE in 2013/14 and £163k/FTE in 2018/19 (averaging at £143k/FTE from 2014-2019). This is an outcome of our successful strategy to broaden and diversify our funding sources (as shown in Figure 7). Our STFC income has remained stable in an absolute sense (and is still the largest single funder), but by 2019/20 accounts for 36% of our annual income with EPSRC at 25%, EU at 16% and commercial funding at 11% (from zero in 2013/14).

### 3.4. Interdisciplinary Research Clusters

Interdisciplinary research centres provide an important strategic vehicle for enhancing the applications of our research and expose us to more opportunities for building partnerships and impact. We have therefore initiated a number of cross-school research clusters:

#### Sussex Programme for Quantum Research (SPQR)

SPQR was formed in 2018 to promote interdisciplinary exchange between world-leading laboratories and translate quantum science from the laboratory to end user applications. SPQR

is one of four Sussex Strategic Research Programmes, so-called to signify substantial investment in areas of existing research strength and address key scientific and societal challenges. SPQR is led from P&A by Krüger and Dalton and brings together expertise from Neuroscience, Engineering, Informatics, Life Sciences, Medicine and Psychology, forming a single network of collaborative, translational research. SPQR links enabling and foundational science with quantum device development, realising applications that range in scope from human brain activity mapping to next generation touch screens, and from microscopic imaging of molecular motors to quantum radar.

### **Sussex Centre for Quantum Technologies (SCQT)**

Major investment by the University and consequent significant grant income have transformed Sussex into one of the leading incubators of quantum technologies. The Sussex Centre for Quantum Technologies (SCQT) is led by Hensinger and Dunningham and is a key component of the broader quantum programme (SPQR). SCQT focuses on the development of novel quantum technologies, in particular, quantum computing, quantum sensing, quantum imaging and simulation, and atomic clocks. Eight research groups, comprising around 100 researchers, work in dedicated, state-of-the-art laboratories in close collaboration with industry partners. SCQT hosts one of the largest ion trapping centres in the world. Key successes include major impact on policy (ICS#2), coupled with high-profile public engagement and crowned by the successful spinout of [Universal Quantum](#) (ICS#4).

### **Data Intensive Science Centre at University of Sussex (DISCUS)**

The Data Intensive Science Centre at University of Sussex (DISCUS) aims to apply advanced data analysis, machine learning, artificial intelligence, computational modelling, simulation and statistical methods to addressing significant interdisciplinary research challenges. It was founded by P&A and now includes researchers across the University. A primary motivation is to align the data intensive technology in P&A to the UKRI and UK industrial strategy agenda on data economy and global challenges. DISCUS facilitates interdisciplinary research collaborations, seminars, workshops and external engagements. University funding includes a part-time Centre Manager. DISCUS key achievements include: Wellcome Trust funding, the STFC-funded CDT, DISCnet (Section 4.6), STFC-GCRF funding for AstroCast, Outputs [doi.org/10.1016/j.rse.2020.111886](https://doi.org/10.1016/j.rse.2020.111886) (submitted to UoA9 and UoA14) and [dx.doi.org/10.1016/j.neuroimage.2015.02.037](https://dx.doi.org/10.1016/j.neuroimage.2015.02.037) (submitted to UoA9 and UoA4), and ICS#3.

### **3.5. Laboratory Estate, Technical Infrastructure and Support Staff**

Strong investment in new researchers was accompanied with a significant upgrade and expansion of our technical infrastructure.

Since 2014, five new laboratories were installed, including a photonics laboratory, three laboratories for MP and a laboratory complex of five laser rooms with associated preparation space, electronics workshop, and meeting room. We also added two clean-rooms, which allow detector work for neutrino research and micro-fabrication of quantum devices. Finally, an electronics laboratory has been installed, aiding research into the trigger design of ATLAS and the next linear collider. The total space occupied by P&A increased from 3537 m<sup>2</sup> in 2013 to 4056 m<sup>2</sup>, while the laboratory space expanded from 934 m<sup>2</sup> to 1140 m<sup>2</sup>.

In addition to the laboratory space, we invested in laboratory facilities such as atomic force, Fourier transform and Raman microscopes, UV-Vis-NIR spectrophotometers, mechanical test equipment, and electrical and electrochemical test facilities. A state-of-the-art aerosol jet printer for high-resolution deposition of electronic devices was recently acquired. An optical frequency comb and a GPS disciplined oscillator is shared between labs.

The technical support for our experimental activities is provided by a state-of-the-art mechanical workshop with significant experience in high-vacuum and low-temperature systems, and working with specialist materials. An additional small mechanical workshop provides on-hand training for PGRs and Fellows in machining; this also permits research staff to do certain jobs themselves.

We provide electronics support in a small workshop staffed by a team of technicians with specialist skills, such as data acquisition, mixed-signal electronics and FPGA programming.

The theoretical and modelling activities are supported by our high-performance computing facility which has grown significantly since 2014. The University is certified as a GridPP Tier-2 site and will enable the ATLAS Virtual Organization (VO) to become fully integrated with the ATLAS Grid. The University has set out an ambitious *Enabling Research Technology Strategy, 2020-2025* that aims to transform the IT provision for researchers.

Beyond the technical and infrastructure support, administrative support is essential to our strategy to increase research funding income, generate impact and maintain the high quality of our research outputs. Our overall professional services staff grew from 1.3 FTE in 2014, to 7.5 FTE now. We currently have 0.8 FTE Research Development Officer to support grant preparation, 1.0 FTE Research Finance Officer to support grants post-award, 2.3 FTE clerical staff for PGR support, 1.3 FTE Business Development Fellows and 2.1 FTE Project Management and Centre Administrators.

### 3.6. EDI in funding and facilities

The support provided for pursuing research funding is described in Section 2.1 and Section 3.2 and is available equally to all, though benefits early career researchers and people returning from care leave in particular (see Box 2):

Pasquazi benefitted from our strong support for funding applications and flexible working policy before and after her maternity leave. This included relief from teaching and administrative duties and extensive support from our Innovations Partnership Fellow as well as School funding for: preliminary results and establishing collaborators; a market study for commercialisation; interview practice with a coach; and for her partner to accompany her to interviews during pregnancy. This helped her secure four grants worth £2.4M.

*Box 2: Case study of research success following maternity support.*

P&A has been proactive in improving access for differently-abled people:

- We installed two stair-lifts to enable wheel-chair use in all areas of our buildings
- We installed automatic door openers on offices and labs
- We modified fire doors to improve emergency egress without assistance
- We introduced emergency evacuation system for mobility-impaired people
- We provide motorized desks for effortless adjustment of the working position

### 3.7. Support specifically for generating Impact

We have invested in business development staff to work with our academics and optimise impact (see Section 3.4). We were awarded four-year STFC Innovation Partnership Fellow funding in collaboration with SEPnet and Portsmouth and created two posts, one at each institution. We have since made this Grade 8 post permanent; the appointment was so successful that we recruited one additional 0.5 FTE Fellow supporting SPQR. These Fellows identify funding avenues and disseminate opportunities; they interact with academics to understand the commercial potential of research and seek external partners to progress projects.

We also put in place Centre Managers, Communications and Operations Officers and Research Administrators for our interdisciplinary centres (2.1 FTE). They facilitate interdisciplinary interaction, project development and communications through publicity, seminars, networking and hack events.

Response-mode funding schemes were deployed to explore proof of concept ideas through small awards (£5-15k). These schemes are financed through a devolved HEIF allocation of £25k p.a. (£40k in 2020) and the STFC IAA (£255k since 2016). We have also accessed the Sussex ESRC IAA and the Sussex GCRF QR funds. Promising proof of concept projects are supported by the STFC Innovation Partnership Fellow to secure additional funds and take ideas forward. For example, small grants from HEIF and the STFC IAA for proof-of-concept work enabled

ATLAS trigger technology to secure a further £115k from the STFC Follow on Fund. Support from companies (Moogsoft and Dyn) then enabled development towards internet security applications.

We make extensive use of institutional support through a central business development team, Innovation and Business Partnerships (IBP), formed in 2016, and Sussex Innovation Centre (SINC). IBP guide on issues such as non-disclosure agreements, intellectual property and research and consultancy contracts, ensuring we have legal cover to work confidently with industrial partners. The IBP team also assist us to work effectively across the University. For example, through the Knowledge and Exchange network meetings organised by IBP, contacts have been shared to support NHS partnership work for COVID modelling. P&A has embedded working relationships with a number of companies based at SINC, including [AMD](#), [cdo<sup>2</sup>](#), [Ambiental](#). Furthermore, P&A makes excellent use of the SINC marketing and commercialisation expertise to frame exploitation plans for new technologies: a student consultancy contract between DISCUS and SINC which will allow PGRs to work on industry challenges is under development.

The central communications team support and amplify our public engagement work externally and identify platforms and media to optimise messaging. This has been particularly useful for SPQR, building awareness and cultivating contacts through broad-interest open days and events.

### 3.8. Collaborative infrastructure

Our particle physics and astrophysics research employs the best international facilities and experiments. Participation is effected through open competition, by securing roles in international collaboration (see Section 4.1) and, where necessary, through direct investment (e.g. 4MOST and JCMT Section 3.2). We work with the following laboratories:

- CERN (ATLAS)
- Fermilab (DUNE and NOvA collaborations)
- SNOLAB (SNO+ and DEAP)
- HENDEL and MLF facilities at J-PARC (JSNS2)
- CHEP (future colliders)
- PSI (nEDM)

We also have access to the Dark Energy Survey, GAMA and DEVILS, and Simons Observatory. We actively participate in a range of projects accessing UKRI supported facilities, including ESO and ESA facilities, and are engaged in extensive collaborations that utilise national and international High-Performance Computing facilities, including DiRAC (via the Virgo Consortium), PRACE, and NCSA.

Additionally, we have made use of collaborative microfabrication facilities, including the Southampton Nanofabrication Centre, the Army Research Laboratory in Adelphi and EPFL in Switzerland.

### 3.9. Usage of non-UKRI Facilities

We enjoy notable success in obtaining access in open competition to non-UKRI funded international facilities. A particular highlight is our success in obtaining time on international HPC facilities, with an in-kind income estimated at >£17.5M (see Table 1). The value of time on large international experiments (e.g. NOvA, DES, GAMA) is harder to estimate, but our access to the NOvA experiment alone has an estimated value of £10M.



Facility	Sussex Investigator(s)	Time Awarded [M core-hours]	Approximate Value [£M]
PRACE	Iliev, Hindmarsh	250	12.5
INCITE	Iliev	94	5.0
Julich SC	Iliev	23.5	1.1

Table 1 Time awarded in open competition on non UKRI Facilities.

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

Engagement, collaboration and partnership with diverse stakeholders, on different geographical scales, is fundamental to the success of our research strategy and the discipline. Our aim is to engage widely and develop significant partnerships, influence national and international priorities and respond to opportunities with agility. Relationships with key partners are shown below.

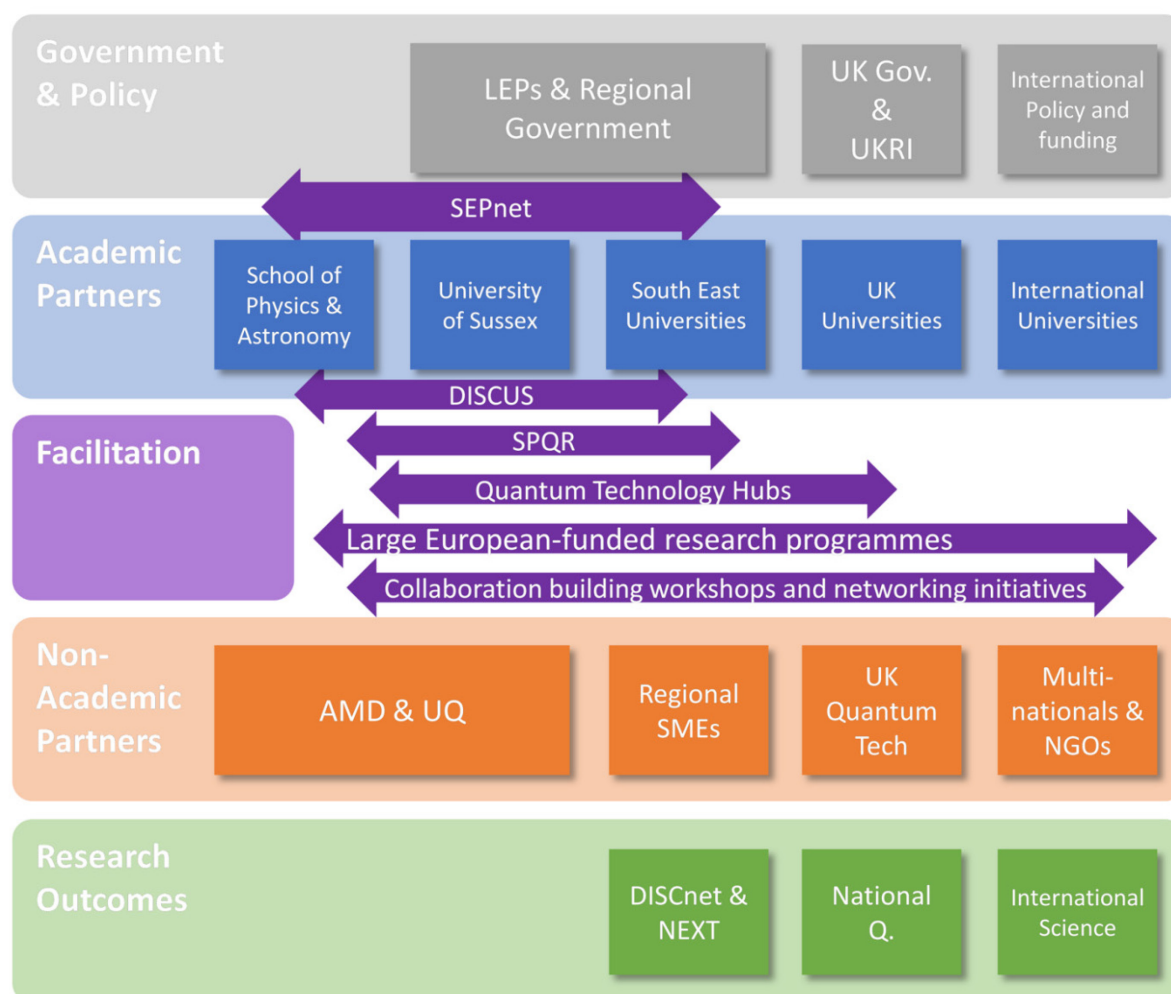


Figure 8: Schematic diagram of the relationships between P&A and our partners.

#### 4.1. Research Collaboration

##### Institutional

Collaboration with colleagues on the same site is essential for generating ideas and eliciting rapid feedback. Our research clusters, DISCUS and SPQR, facilitate interdisciplinary interaction (Sections 1.4, 3.4) and yielded 3 interdisciplinary Outputs submitted to UoA9 (and UoAs 4 and 14) and ICS#3.

**Local and regional**

The clear value of local and regional academic collaboration led to our co-founding the South-East Physics Network (SEPnet) in 2008 - since extended to 2023 and expanded to nine departments. SEPnet pre-empted the UK “Place” agenda (articulated in the Industrial Strategy 2017) and offers many benefits (Sections 4.3, 4.6). Directly translatable advantages for our research from this regional critical mass include economies through common/shared facilities (e.g. the Southampton Nanofabrication Centre), collaboration for funding e.g. the successful TPP collaboration with RHUL and UCL via NExT and, through the expansion of graduate training opportunities and funding (from GRADnet and DISCnet, Section 4.6), and the growth of our research community.

**National**

To ensure that the UK remains an international leader in quantum technology, linking individual University laboratories through the UK National Quantum Technologies programme was essential. P&A was influential in developing the national strategy (see ICS#2) and is the main partner in the EPSRC Hub: Quantum Computing and Simulation and in the UK Quantum Technology Hub: Sensors and Timing. This provides access to common facilities, increased research grant income (Section 3.3) and strong exposure to the UK commercial sector (Section 4.2).

Other UK-focussed partnerships include collaboration between EPP and TPP members with the Institute for Particle Physics Phenomenology (IPPP) in Durham (Jaeger as IPPP associate), alongside projects with the National Physical Laboratory and the Rutherford Appleton Laboratories.

**International collaborations**

We have many international collaborations and 84.9% of our research publications (2014-2020) have international co-authorship (c.f. e.g. University of Oxford 78.5%). Collaborations are initiated, developed and maintained through fora (e.g. P&A organised 4 Lorentz Centre meetings) and networks such as European COST Actions.

A key priority is building strategic, institutional relationships and these are recognised with e.g. Dalton’s visiting Professorships at the University of Malaya, the Kazakh National University, the University of Texas and King Saud University. Hindmarsh’s engagement with the University of Helsinki resulted in €1M funding from the Academy of Finland. Other visiting positions include Wilkins at Universities of Texas, Austin and Malta. Likewise, a strong relationship with the Weizmann Institute, facilitated by Sussex co-funding, enabled funding of two female PhD students.

We have prominent leadership in large collaboration funding e.g. Oliver led the EU-funded €2.5M multi-institution Herschel Extragalactic Legacy Project, while Hensinger and Weidt are part of the European Quantum Flagship collaboration for microwave-driven quantum computing with trapped ions.

**Collaboration to build and exploit major international facilities**

Much of our world-leading research is only achieved through £Bn facilities, necessitating significant international collaboration. We are active partners and position ourselves to take leading roles in areas aligned with our specialist expertise. We enable those achieving key roles to fulfil them, providing extensive and bespoke institutional support.

We play leading roles in current astrophysics survey experiments including: CEERS, CLASSY, COSMOS, DES, GAMA, HERMES, JINGLE, LOFAR, MIGHTEE, Planck, the Simons Observatory, VIDEO, and VEILS. Our investment in 4MOST (Section 3.2) provides membership and leadership through Loveday as European chair of the WAVES management group. P&A is a member of the Euclid, LISA, LSST and SKA consortia where e.g. Sargent holds the co-chair of the Extragalactic Continuum SWG and Iliev leads simulation efforts focussed on the Epoch of Reionisation. Wilkins is involved in multiple JWST surveys.

P&A shows international leadership in collider physics, neutrino physics and neutron EDM. We have strong research collaborations globally, in particular with the international laboratories CERN (ATLAS collaboration, future colliders), Fermilab (DUNE, SBND and NOvA collaborations), SNOLAB (SNO+ collaboration), J-PARC (JSNS2 collaboration), and PSI (nEDM). We are also part of the International Linear Collider and are supported by the EU (H-2020) for future collider R&D (AIDA2020, AIDAInnova and FEST grants).

P&A has a strong record of filling responsible roles within the ATLAS experiment, including SUSY Co-convenor, Run Coordinator, Upgrade HTT project leader, ID Trigger co-convenor. We facilitate this by relieving staff of teaching commitments, enabling them to be based at CERN for most of their time.

## HPC

Modern, large, galaxy formation simulations require pooled expertise from international consortia. We are a founding member and second largest node of the highly successful Virgo Consortium for Cosmological Simulations, in addition to playing a leading role in several other collaborations including MassiveBlack, CODA, and Bluetides. We make extensive use of grid resources on the WLCG. Sussex is also a certified GridPP Tier-2 site, generating several million CPU-hours annually from the national supercomputing service CSC. We are also part of the JADE 2 collaboration, securing funding worth £5.5M from EPSRC for GPU computing facility in Hartree.

## 4.2. Research User Engagement and Contributions to the economy and society

P&A has cultivated partners through strategic initiatives in quantum and related technology and data science. A key factor has been enhanced professional support, including dedicated innovation and business Fellows (Section 3.5) who have fostered a steadily increasing portfolio of collaborations between 2014 and 2020. Our strategy has also built on local, regional and national structures to increase our visibility and enhance engagement.

These initiatives have led to significant growth and diversification of funding for research and interdisciplinary collaborations (Section 3.3).

## Data Science

DISCUS is now firmly established as a conduit to interdisciplinary research and knowledge exchange projects with external audiences.

DISCUS aims to be a trusted partner in delivering a digital revolution for our region. P&A played a leading role in the organization of local data science industry networks e.g. initiating the [Sussex Data Science Meetup](#) in 2018 – which now has 400 members. These relationships led to the formation of [DataJavelin](#), a data science consultancy.

Data science engagement with regional business, particularly SMEs, has been facilitated through existing SEPnet employer engagement and presence on the advisory board of the South Coast Centre of Excellence in Satellite Applications. The DISCnet CDT (Section 4.6) led to PGR placements and we have maximized opportunities for cooperation with the local digital economy through our links with Sussex Innovation Centre. Examples include developing an AI image analysis tool for a Brighton start-up, [Deckchair](#), and work with [Moogsoft](#) on the use of techniques developed for the ATLAS trigger in cyber security applications. A student consultancy scheme is being established with the Sussex Innovation Centre and will increase this type of engagement.

Extending our reach nationally, DISCUS worked in partnership with the STFC Food Network+ (Oliver as Data Science Champion) to build links with the UK food industry. One successful outcome was a collaboration with the Met Office on modelling crop yield, resulting in a refereed publication and Agriculture and Horticulture Development Board funding for a PhD student.

A major impact from DISCUS has been a publication (submitted to UoA9 and UoA14) which was co-produced with National Drought Management Authority in Kenya and addressed drought forecasting in Africa – this is outlined in ICS#3.

### Technology Transfer

We have focused on developing significant relationships with key partners. Foremost amongst these are two companies that we initiated: [Advanced Material Development](#) (AMD, #ICS1) and [Universal Quantum](#) (ICS#4). Both have provided direct inward research investment – AMD, for example, has funded five Research Fellows.

Through the Sussex Programme for Quantum Research (SPQR), P&A has attracted inward investment for research and formed original internal collaborations – notably with the School of Engineering and Informatics and Brighton and Sussex Medical School. These have opened up novel research directions and we anticipate new funding streams (Section 3).

SPQR has fostered cross-disciplinary bids collaborating with multiple partners, both academic and industrial (e.g. IUK Commercializing Quantum Technology: Large Collaborative Projects). One such partnership around environmental RFID tags, involving the [Sussex Digital Futures at Work Research Centre](#) in [Sussex Business School](#), AMD and Walmart, resulted in a Joint UKRI Fellowship award.

Productive links to industry in the quantum technology sector have been facilitated through our public engagement strategy (Sections 1.3.1, 4.3, ICS#4), our regional engagement with policy makers and (ICS#2) involvement in the UK Quantum Technology Hubs. The publication of the first blueprint for a quantum computer, in partnership with international academic partners and Google, has been a major catalyst for promoting engagement.

Links generating e.g. research funding, patents and joint publications have been established or developed with e.g. [AMTE Thurso](#), [Allianz Rubber](#), [Allectra UK](#), [M Squared Lasers](#), [cdo<sup>2</sup>](#), [Leonardo](#), [Torr Scientific](#), [TMD Technologies](#) and [HighFinesse](#), UK and US defence organisations and a major international financial company. Partnering with the second largest UK battery factory, AMTE Thurso, led to an Innovate UK grant to develop quantum sensors for end-of-line battery testing (worth £.5M) and contribution to the first UK 'gigafactory' for large-scale battery production. Concurrently, work to develop a quantum microwave sensor support with Leonardo secured a 5-year, £1.5m, EPSRC Quantum Technology Fellowship (Verdu) and generated two patents.

### 4.3. Public Engagement

In partnership with SEPnet, we established a highly successful outreach and public engagement programme, which has fostered enduring relationships with local schools. This had prioritised undergraduate recruitment but since 2014, we have expanded and refocused our programme to solicit the engagement of targeted audiences.

To facilitate this expansion, and in addition to substantial departmental resources, we gained support from the Royal Society, STFC, the Royal Astronomical Society, and the Ogden Trust, and have partnered with schools, charities, local government, museums and science discovery centres.

From STFC alone, we have attracted over £250k of funding for public engagement, including the award of two Public Engagement Fellowships – more than any other institution.

Highlights of our programme include:

- The innovative [Science on Buses](#) initiative (Asquith)
- Leadership (Shaw) of the [ATLAS Open Data Project](#)
- Participation in the [ICTP Physics Without Frontiers](#) programme (led by Shaw)
- Installation of four exhibits around ATLAS and [James Webb Space Telescope](#) (2013/2014 and 2018/2021 respectively) at the Royal Society Summer Science Exhibition

Also of note is our promotion of emerging quantum technologies, including contribution to exhibitions on quantum computing and cryptography at the Science Museum group of museums (ICS#4) and presentations at [Wired Sussex](#), an annual festival for our local digital business community.

#### 4.4. Research Influence and Contribution to the Discipline

P&A has sought not only to respond to national and international priorities and initiatives, but also to influence and even pre-empt key aspects.

##### Strategical influence on the national and international research agenda

Our role influencing national and international policies on funding for quantum technology is significant and contributed e.g. to the allocation of £1Bn government investments, described in ICS#2.

P&A has also contributed to international research strategy, e.g. Sanz was a member of the Physics Preparatory Group producing recommendations for the latest European Strategy for Particle Physics (2019).

We have been active in steering UKRI through advisory structures, e.g. the STFC PPAN 2017 Balance of Programmes exercise (De Santo). We also provided input to the STFC Corporate Plan via the Skills and Engagement Advisory Board (Oliver). Since 2016, Oliver has chaired STFC's Education, Training and Careers Committee and has guided: the introduction of Data Intensive Science CDTs to the STFC portfolio (allowing STFC to secure ~80 new students in 2017, from a UK skills initiative, at a higher pro-rata rate than other councils); the introduction of the first UKRI PhD accreditation scheme; and revision of the Ernest Rutherford Fellowship criteria. Hensinger serves on EPSRC's Physical Sciences Strategic Advisory Team.

##### Contribution to the operation on fellowship panels, grants committees

P&A is a major contributor to UK research infrastructure. Research Fortnight (RF 458, 10 June 2015) reported that Sussex was ranked 1<sup>st</sup> (of 22) for their acceptance rate (92.3%) of peer reviewing for STFC.

Our emphasis on Early Career Researchers (Section 2) is reflected in our contribution as fellowship panel members (or **Chairs**):

- UKRI Future Leaders (Oliver, Pasquazi, Sanz)
- UKRI Stephen Hawking (**Oliver**)
- UKRI Alan Turing Fellowship (Oliver)
- STFC Ernest Rutherford (Falk, Litim, **Oliver**, Sanz)
- EPSRC fellowship (Dunningham, Hensinger, Keller)
- STFC CERN Fellowships (Asquith)
- Marie Skłodowska-Curie Actions Individual Fellowships (Pasquazi)
- Royal Society Newton International Fellowships (Asquith)
- Royal Society University Research Fellowships (Hindmarsh)

We also contribute significantly to UKRI funding panels:

- EPSRC Centres for Doctoral Training Panel (Hensinger)
- EPSRC grants Panel (Dunningham, Garraway, Keller)
- STFC Particle Physics Grants Panel (De Santo)
- STFC Projects Peer Review Panel (Iliev, Peeters)

This extends to international funding committees:

- Academy of Finland Physics 1 Grants Panel (**De Santo**)
- NSF proposal review panel (Iliev, Sargent)
- PRACE Tier-0 panel (Iliev)
- US Department of Energy (Hensinger)
- Novo Nordisk Foundation (Hensinger)
- [NCN Poland](#) - Expert Panel for POLS call and Sonata Call (Vivarelli)



P&A contributes widely to journal editorship and peer review. For example, Peccianti is Chief Editor of Frontiers in Photonics and Associate Editor of Optics Express, and we have four Associate Editors of Scientific Reports (Nature).

#### 4.5. Recognition of Excellence

P&A has delivered invited lectures at international conferences of note e.g. Peccianti was general chair of Integrated Photonics Research at OSA Advanced Photonics in 2019.

More specific recognition comes with the number of prestigious fellowships awarded in P&A:

- STFC Ernest Rutherford (Lindert),
- STFC Public Engagement (Romer, Wilkins)
- Royal Society URF / Dorothy Hodgkin (Asquith, Byrnes, Fialkov)
- Leverhulme Senior Research Fellowship (Sargent)
- Marie Skłodowska-Curie Actions Individual Fellowship (Pasquazi)
- EPSRC UKRI Innovation Fellowship (Pasquazi)
- EPSRC Quantum Technology Fellowship (Verdu)
- CERN scientific Associate (Vivarelli)

Others won ERC Consolidator awards (Lewis, Peccianti) and ERC Starter Awards (Hartnell, Pasquazi, Seery), while De Santo received a Royal Society Wolfson Research Merit Award. As a key member of the Planck Team, Lewis was awarded the Gruber Cosmology Prize (2018), while Peeters received a Breakthrough Prize (2016) in Fundamental Physics as a member of SNO Collaboration.

#### 4.6. Co-operation and collaborative arrangements for PhD training

P&A's proactive approach to PGR recruitment and training is amplified by our engagement with GRADnet and DISCnet. GRADnet, the collaborative graduate school of SEPnet, is the largest regional training programme for Physics PGR in England, offering comprehensive technical and transferable skills training alongside career development and employment opportunities.

Our approach is further illustrated by the NEXt regional alliance, comprising core partners Sussex, Southampton, RHUL, QMUL, RAL and KCL. With members of P&A in key steering roles from the outset, the NEXt alliance has maintained a Graduate School since 2008, operating via shared video teaching and biannual workshops. Since 2011, PGR training is additionally facilitated through annual and STFC co-funded Summer Schools, offering international expert lectures and dedicated sessions on careers, employability, diversity, and public engagement, attracting typically 45-50 participants UK-wide.

DISCnet is the Data Intensive Science Centre for doctoral training within SEPnet. Starting as one of eight STFC-funded CDTs in 2017, with core partners Sussex, Southampton, QMUL, Portsmouth and Open University (together accounting for 10% of UK's STFC activity), DISCnet has secured funding for 31 four-year PhD studentships (2017-2019 entry) and a further 25 students since. Sussex has commanding leadership in DISCnet, with Oliver as Director and sixteen student members. DISCnet provides training and non-University placements, utilising a network of around 70 partners. The DISCUS/DISCnet-run STFC Data Science Summer School at Sussex in 2019 attracted over 100 PGR, with 92% of attendees awarding a score of >7/10 and opting to recommend the Summer School. An STFC review of their eight CDTs graded DISCnet and one other CDT 'A'.

Strong international links fostered our partnership in the Marie Skłodowska-Curie Innovative Training Networks (ITN) LIMQUET and Enabling Excellence. LIMQUET has ten partners from five countries and supports fifteen PGR. Exemplifying successful career progression, Sussex Enabling Excellence graduate Sebastian Nufer now heads the Research & Development division at Swiss sensor technology company Sensirion.