

Institution: Queen Mary University of London
Unit of Assessment: 9 Physics
1. Unit context and structure, research and impact strategy

1.1 Overview

Since REF2014, QMUL's School of Physics and Astronomy has undergone transformative change: research income has increased very significantly, and we have attracted many outstanding scientists with distinguished fellowships – making us home to the most UKRI Future Leaders of any Physics department in England. Our building has undergone a complete renovation and we have invested in our research infrastructure. Specifically:

We have hosted **22 distinguished fellowships:** 14 early-career (13 proleptic), 1 senior and 7 for existing staff, including 3 UKRI Future Leaders Fellows (see [Section 2.1](#))

Our annual average research award has **increased by over 20%** (see [Section 3.1](#))

We have completed a **£12M renovation of our building (of which £3M for labs)**, including new interaction areas and research infrastructure (see [Section 3.3](#))

We have considerably **increased the number of research students (62% increase p.a.)**, with dramatically improved four-year submissions (see [Section 2.3](#))

We now **lead two internationally renowned training networks** (see [Section 4.1.3](#))

Improvements in key metrics since REF2014 include:¹

	REF2014	REF2021
Research income (total)	£18.5M	£29.8M
Research awards	£24.6M (£4.9M p.a.)	£41.5M (£5.9M p.a.)
Income-in-kind (research council facilities)	£1.3M (£260k p.a.)	£45.6M (£6.5M p.a.)
Staff numbers submitted for REF (in FTE)	Out of 48.8, 24 submitted in UoA9 and 10 in UoA13b	48
New appointments (in FTE)	15	24.4
Number of independent fellowships	10	22
PhD awards	53 (10.6 p.a.)	120.2 (17.2 p.a.)
Investment in building/infrastructure	£6.5M	£12M
EDI status	Juno Practitioner	Juno Champion + Athena SWAN silver

¹ 10 academics from the School were submitted to UoA13b in REF2014. Unless indicated otherwise, figures relating to REF2014 refer to the whole School irrespective of UoA.

Unit-level environment template (REF5b)

The School is submitting 48 FTE academic staff, supported by 32 RAs, 7.5 academic-related staff, 5 technicians and 14.8 support staff. Research takes place across four distinct – but interconnected – research centres: **the Astronomy Unit (AU), Centre for Research in String Theory (CRST), Particle Physics Research Centre (PPRC), and Centre for Condensed Matter and Materials Physics (CCMMP** – a new addition since REF2014, previously submitted within UoA13b). These centres have played a key role in numerous high-profile scientific success stories, from the discovery of the nearest exoplanet to the Solar System, Proxima b, to directing United Nations policy on nuclear waste storage. **Our research is published in preeminent journals**, with 348 papers in *Astrophysical Journal Letters*, *JCAP*, *JHEP*, *Nature*, *Nature Astronomy/Materials/Physics*, *Physical Review Letters*, *Science*, or *Science Advances*.

1.2 Research and impact strategy: this REF period and beyond

Our REF2014 research vision aimed at increasing the **quality, volume and impact** of our research, and our strategy has proven successful. Building on this, we contribute to our [University's 2030 strategy](#) to carry out distinctive, world-leading research – both applied and curiosity-driven – that brings lasting social, cultural and economic impact. To achieve this, we...

1. ...enhance our research base by hiring high-calibre researchers

We have recruited **13 exceptional early-career fellows on proleptic appointments** (see *Table 1*); attracted senior figures with outstanding research profiles (Green FRS and Perry); and appointed staff with expertise spanning several of our centres (Baker, Blumenschein, Cremonesi, Vegh and White) to **increase the interdisciplinarity** of our work and strengthen links between these research centres. **Supporting fellows by making proleptic appointments** will remain a pillar of our strategy. **Expanding the neutrino group** will also be a priority for the next REF.

2. ... work to increase and diversify our income

Alongside enhancing our STFC research income, **we will continue to seek – as we have already successfully done – funding from other sources** (see *Figure 1* below). We run writing retreats and sandpits to encourage innovative thinking, organise grant-writing training for all staff (including bespoke early-career sessions), and horizon-scan for new grant opportunities.

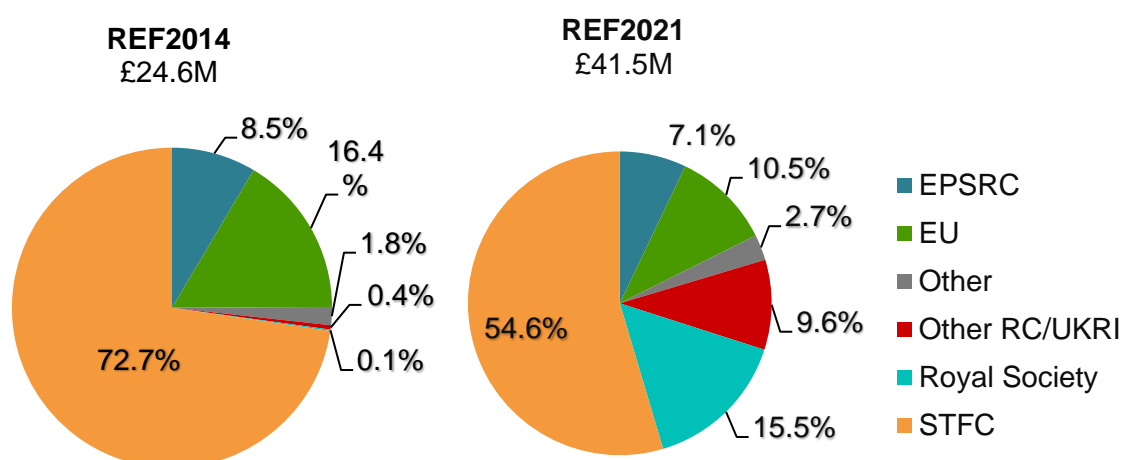


Figure 1. Total research award value by funder.

As a measure of success so far, the School has seen a sustained increase in awarded grants (from **£2.4M** in the first REF year to **£12.7M** in 2019/20, see *Figure 4*); hosted **22 Individual Fellowships** from the ERC, Royal Society (including significant top-up funding), Royal Academy of Engineering, STFC and UKRI (Future Leaders Fellowships/FLFs); and leads two internationally renowned flagship collaborations (ITN SAGEX, PI Travaglini, €4M; EPSRC-funded DCE-CDT, PI Rizvi, £1.6M; see [Section 4.1.3](#)).

3. *...are always pushing interdisciplinary research*

We strive to **work beyond the traditional boundaries of physics** – applying string theory methods to computational linguistics, for instance, or using machine learning methods to model air pollution in Mexico. Much of this work is accomplished in interdisciplinary centres within QMUL such as the Materials Research Institute ([MRI](#)) and Institute for Applied Data Science ([IADS](#)) (see [Section 3.3.1](#)). Such innovation has led us to **partner with prestigious consortia** such as the EPSRC Networking Centre of Advanced Materials for Integrated Energy (CAM-IES); **expand a collaboration between CCMMP and PPRC** on the design of organic semiconductor radiation detectors and bent silicon sensors for particle physics applications and semiconductor-based neutron particle detectors for border security (funded by the Atomic Weapons Establishment Ltd. (AWE) and STFC); **receive funding** from the Global Challenges Research Fund; and **be invited to present** at industry-facing events such as CogX. We encourage close collaboration between our Centres via funded joint equipment bids, our School Colloquium programme, and interdisciplinary PhD training, and offer bespoke industry secondments for PhD students through our training networks (see [Section 4.1.3](#)).

To achieve **lasting impact**, we...

4. *...address challenges that are high priorities for industry and society*

From the very beginning of our research planning process, **impact is top priority** – as reflected in our chosen case studies: Saturn, Radiation, Exoplanets, and Schools. To magnify the impact of our work, we **contribute unique expertise to international collaborations**, from the NASA-ESA Cassini mission (Saturn) to the UK's flagship molecular dynamics simulation software DL_POLY (Radiation), and **target impact in the broadest possible sense**, with beneficiaries ranging from private enterprise (Exoplanets) to intergovernmental organisations such as the International Atomic Energy Agency (Radiation), school students (Schools), and the general public (Saturn). Beyond these case studies, our **industrial contacts span sectors including data science, financial services, technology, museums, government/policy bodies, oil and gas and logistics**, and have given rise to Innovate UK Knowledge Transfer Partnerships. We recently launched the School's **first successful spin-off company**, Chromosol Ltd – a winner of the prestigious Royal Society of Chemistry Emerging Technologies competition (enabling technologies, October 2020).

In 2020 we formed a **multidisciplinary radiation detector group** to focus on applications of radiation to fundamental science and to society. Technology required for precision measurements of the Higgs boson can be used in the nuclear industry as part of the UK and global strategy for achieving a balanced energy portfolio for a carbon-neutral future, and for medical applications. As part of our **future strategy to expand multidisciplinary research**, we aim to transform this newly formed group into a **recognised global centre of excellence** in the next REF period, generating impact from our existing core competency.

5. *...invest in public engagement*

Our full-time Public Engagement Officer has designed a **bespoke outreach strategy to maximise the efficacy of our work** (see [Section 4.4.1](#)). The QMUL Press Office works

with academics to ensure our major discoveries (e.g. Proxima b) receive large-scale international media attention; the School has a well-attended evening lecture series for the general public and science journalists; and academics regularly contribute to high-profile media such as the *BBC*, *The Guardian* and *New Scientist* (e.g. Berman, Murray, Spence). Going forward, **we will formulate an outreach and schools-targeting strategy that effectively utilises our resources, embedding outreach at all levels of the School.** Identifying schools that would benefit from our engagement will form the basis of the expansion of our outreach.

Finally, we...

6. *...embed equality, diversity and inclusivity (EDI) in everything we do*

The School holds **Juno Champion and Athena Swan Silver awards**, and EDI is a standing item on the agenda of all School committees. To maintain a safe, professional and inclusive working environment, our dedicated EDI committee oversees key processes such as recruitment, career progression and promotion, allocation of management and administrative responsibilities, and flexible working and parental leave. **We have pioneered a 'Parental Leave+' scheme**, guaranteeing academics a PDRA to maintain their research. Looking ahead, **we are leading new institutional-level initiatives to attract BAME students into research career pipelines**, including: mentored research internships for undergraduate BAME students; revising PhD application processes to recognise competencies as well as qualifications; and launching pre-application workshops to overcome self-confidence barriers.

7. *...support openness and integrity*

The School supports open-research principles, creating publicly accessible codes, tools and data repositories. **All research papers are publicly accessible** via the [QMRO database](#), and the arXiv and SCOAP3 repositories. This open environment feeds into our wider work – for example, PPRC uses CERN Open Data for GCSE and A-level outreach work and undergraduate teaching activities, and the UK HepData repository for data archival. Our research integrity (mentoring, code of conduct) is safeguarded by our comprehensive peer review of grant applications, our Graduate Degree Committee, university level processes (see REF5a, Section 2) and is also underpinned by our **membership of (inter)national grant panels and learned societies** (see [Section 4.2.3](#)). Highlights of publicly accessible outputs include:

AU	Placed N-body simulation code gevolution on GitHub for public access
CCMMP	Made CamCASP tool, for modelling intermolecular interactions, open access and licensed it to over 60 commercial groups; developed and distributed DL_POLY code, the flagship code for simulating molecular dynamics, to over 4,200 users worldwide (840 UK) with support from several EPSRC grants
CRST	Launched amplitudes.org , an open repository of theoretical results and tools in scattering amplitude calculations, and the ongoing legacy of SAGEX
PPRC	Made all published measurements available on the HEPData repository; implemented new machine learning tools in the open-source ROOT data analysis framework used universally in particle physics

Delivery of strategy

The School Research Committee provides leadership, monitoring, annually evaluates the above goals, and identifies key infrastructure and equipment needs. It is chaired by our Director of Research (Travaglini) and includes a dedicated Research Manager (post created in 2017), Director of Impact, Group Heads, Director of the MRI, Director of Graduate Studies, Head of School, School Manager and two EDI representatives. The Director of Research is also a member of the School's Senior Executive Group, ensuring that decision-making is informed by research priorities. Our Research and Graduate Degree Committees ensure that best practice is shared between Research Centres.

1.3 Research centres: strategy and objectives**The Astronomy Unit (AU)**

The **AU** comprises three groups – Cosmology, Planetary Systems and Space Plasma Physics – that address some of the most topical questions in astronomy, including two of the STFC's three key [Science Challenges in Frontier Physics](#):

How did the Universe begin, and how is it evolving?
Cosmology

How do stars and planets form and develop and how do they support the existence of life?
Planetary Systems, Space Plasma Physics

Academic staff: 16.1	PDRAs: 32 (49 years)		
PhDs completed: 22.1	Income-in-kind: £2M		
Articles: 763	Citations: 21,459		
Membership 2.3P, 2R, 4SL, 1L, 6.8 fellows (all proleptic) ²			
	Cosmology	Planetary Systems	Space Plasma Physics
Professors:		Murray (0.3FTE), Nelson	Burgess
Readers:	Clarkson (Director), Malik		
Senior Lecturers:	Clifton, Sutherland	Agnor	Tsiklauri
Lecturers:	Bull		
Fellowship holders:	Baker (RS URF, SL) Mulryne (0.8 FTE, RS URF, SL), Pourtsidou (FLF, R)	Gillen (Winton, L) Haworth (RS DHF, L) Paardekooper (RS URF, SL)	Chen (STFC ERF, L)
Research grant awards: £14.2M			

The *Cosmology* group has a strong record in relativistic cosmology. Mulryne and Malik study the early Universe; Clifton, Clarkson and Baker study cosmological structure formation and extended

² Abbreviations in the group tables: P=Professor, R=Reader, (S)L = (Senior) Lecturer.

Unit-level environment template (REF5b)

theories of gravity. Recent appointments bring expertise in observations and data analysis: Poursidou and Bull, who play leading roles in the Euclid satellite mission, the SKA (Square Kilometre Array) and precursor telescopes (e.g. HERA, MeerKAT). Baker leads two working groups within the LISA (Laser Interferometer Space Antenna) Consortium, ensuring direct involvement in the new field of gravitational wave astronomy. The tight-knit focus and range of skills within the group is an incubator for collaborations across theory and observations.

Planetary Systems focusses on solar and extra-solar planets. Murray has elucidated Saturn's complex ring system via his work on NASA's Cassini mission. Haworth, Nelson and Paardekooper simulate how protoplanetary discs and planets form and evolve, leading modelling efforts for ESA's PLATO (PLANetary Transits and Oscillations of stars) mission. Agnor models satellite dynamics and formation, and Haworth provides expertise on observations from ALMA (Atacama Large Millimeter Array). Gillen is strongly involved in the NGTS (Next-Generation Transit Survey) and TESS (Transiting Exoplanet Survey Satellite). The group has an exceptional record in exoplanet detection: Anglada-Escudé led the discovery of a planet in the habitable zone of Proxima Centauri, the Sun's nearest stellar neighbour, and was consequently named one of *Time's* top-100 most influential people of 2017, and a *Nature's* top-10 scientist of 2016.

The *Space Plasma Physics* group focuses on the solar wind and solar magnetohydrodynamics (MHD). Researchers study kinetic and MHD phenomena (Tsiklauri), solar wind turbulence and shocks (Burgess; member of ESA's Solar Orbiter team), and perform observations and data analysis (Chen; member of the FIELDS instrument team on NASA's Parker Solar Probe).

Research strategy

A strategic priority since REF2014 has been to reinvigorate the AU by appointing talented academics, enhancing areas of existing strength and introducing complementary expertise. The AU...

...concentrates world-leading research in Cosmology, Planetary Systems, Space Plasmas, with complementary programmes in theory, observations, and data analysis.

...supported this strategy by hiring **8 early-career researchers** (7 with fellowships).

...is investing in **leadership** and expanding **participation in international priority experiments** such as Euclid, PLATO, VRO and the SKA.

...strives for increased **collaboration in academia and industry** in areas of High-Performance computing and Big Data.

The Centre for Condensed Matter and Materials Physics (CCMMP)

The **CCMMP** has a vibrant, interdisciplinary research programme in experimental, computational, and theoretical condensed matter and materials physics. It leads the cross-faculty Materials Research Institute (MRI, see [Section 3.3.1](#)) and tackles three major research areas, with many researchers addressing several: Materials for Energy and the Environment, Atomistic Material Structure, and Molecular and Quantum Systems. It is expanding into Theoretical Ecology, supported by a large recent collaborative NERC grant (Trachenko).

Academic staff: 10.6 FTE	PDRAs: 22 (26.9 years)
PhDs completed: 51.1	Income-in-kind: £8.5M
Articles: 275	Citations: 4201
Membership 3.6P, 2R, 3SL, 1L, 1 fellow (proleptic)	
Professors:	Dove ³ (0.1 FTE), Drew (Director), Dunstan (0.5 FTE), Gillin, Trachenko
Readers:	Baxendale, Dennis, Phillips ⁴
Senior Lecturers:	Kreouzis, Sapelkin
Lecturers:	Misquitta
Fellowship holders:	Mol (UKRI FLF, R ⁴)
1 experimental support engineer, 1 research officer	
Research grant awards: £3.8M	

Materials for Energy and the Environment: Funded by four EPSRC grants, the group explores organic, inorganic and hybrid materials with technological applications: carbon nanostructures for batteries (Drew), photovoltaics (Dennis, Kreouzis) and thermoelectrics (Baxendale); molecular and framework materials for barocalorics (Phillips); and materials for nuclear waste encapsulation (Trachenko), for which the Centre recently signed a research agreement with the International Atomic Energy Agency (IAEA).

Atomistic Material Structure: From new functional materials to condensed matter theory, CCMMP works to solve fundamental questions by combining simulations and experiments (Dove, Misquitta, Phillips, Trachenko). We (Dove, Drew, Phillips, Sapelkin, Trachenko) intensively use – and are disproportionately successful in being awarded beamtime from – major facilities including the Diamond Light Source, ESRF, ILL, ISIS, PSI and ANSTO, and have led the design, construction and/or commissioning of many instruments at central facilities (including D18 at Diamond Light Source (Sapelkin), HIFI (Drew) and MERLIN at ISIS (Dove)). Simulation expertise ranges from all-electron methods (Misquitta) to DFT (Dove, Phillips) and massive parallel molecular dynamics simulations with very large and world record-breaking system sizes (Dove, Trachenko, Phillips).

Molecular and Quantum Systems: With a focus on carbon-based structures, we study topics pertaining to organic materials, including the coupling of structural and electronic properties of graphene in experiment (Dunstan) and theory (Misquitta); light-matter interactions in molecular systems (Drew, Gillin); electronic structure (Misquitta); quantum tunnelling in graphene-based devices (Mol); and radiation detectors (Kreouzis). Work has been funded by UKRI FLF and RAEng fellowships (Mol), the ERC (Drew), venture capital (Gillin), the Chinese Education Ministry (Drew, Gillin) and the AWE (Kreouzis).

³ Not submitted for outputs but contributing to our environment.

⁴ Promoted after REF period but application submitted within it.

Research strategy

The key aims of CCMMP's strategy are to...

...pursue research across discipline boundaries. We have hosted 3 MRI Fellows and 1 FLF working at the physics-chemistry-materials science interface, all now in permanent academic positions.

...expand into UKRI, GCRF and ISCF priority areas – 'Energy', 'Technology Touching Life' and 'Tackling the Plastic Problem'. Highlights include portable devices for rapid pathogen detection in developing nations (Mol).

...commercialise research using proof-of-concept and industry funding. Our spin-off company Chromosol (Gillin) is valued at £1.6M.

...increase industry-led research with support from InnovateUK grants and host Knowledge Transfer Partnerships.

The Centre for Research in String Theory (CRST)

Building on an exceptional history of achievement and discovery, the **CRST** has long held an outstanding reputation in *String Theory*, and has emerged as a leading centre in *modern scattering amplitudes*, a rapidly growing area at the heart of high-energy physics. It has hired four early-career and two mid-career researchers, all producing pioneering work, and two renowned senior professors (formerly at the University of Cambridge): Green FRS (since 2016, a co-inventor of superstring theory, former Lucasian Professor of Mathematics, Milner Breakthrough Prize) and Perry (since 2019), cementing the centre as one of the leading UK theory groups. CRST focuses on two key areas: *Scattering Amplitudes* and *String Theory* (both intimately linked to STFC key Science Challenges).

Academic staff: 13.4 FTE	PDRAs: 10 (14.8 years)	
PhDs completed: 17	Income-in-kind: N/A	
Articles: 256	Citations: 8,037	
Membership 5.4P, 3R, 5 fellows (4 proleptic)		
	Scattering Amplitudes	String Theory
Professors:	Brandhuber (Director), Spence, Travaglini	Berman, Green FRS (0.2FTE), Perry (0.2FTE), Thomas
Readers:	White	Ramgoolam, Russo
Fellowship holders:	Monteiro (RS URF, L), Wen (RS URF)	Buican (RS URF, SL), Papageorgakis (RS URF, R ⁴), Vegh (STFC ERF, L)
Research grant awards: £7.6M		

CRST academics have made ground-breaking contributions to scattering amplitude research, reimagining quantum field theory using amplitudes as universal building blocks. Our excellence is evidenced by our leadership of the ITN SAGEX (see [Section 4.1.3](#)), "*an Innovative Training*

Unit-level environment template (REF5b)

Network funded by the EU to train the next generation of world-leading scientists". Recent breakthroughs by CRST researchers include characterisation of the double copy for classical solutions in gauge and gravity theories (Monteiro, White), pioneering formulations of amplitudes using ambitwistor strings (Monteiro, Wen), deep mathematical structures of Higgs and gluon amplitudes/form factors (Brandhuber, Spence, Travaglini) and string amplitudes (Green, Wen), and applying amplitudes to gravitational waves (Brandhuber, Russo, Travaglini, White).

School researchers probe the foundations of string theory, M-theory, dualities and supersymmetry, and have expanded their interests to include holography (Ramgoolam, Vegh), novel conformal field theories in various dimensions (Buican, Papageorgakis), black-hole thermodynamics and the information loss problem (Perry), and generalised geometry applied to M-theory (Berman). CRST has made pioneering contributions in the construction of black-hole microstates (Russo) and in opening the field of exceptional field theory (Berman).

Research strategy

Since 2014, the Centre has significantly expanded its expertise and breadth across a range of topics with high international activity.

The CRST aims to...

... strengthen core research strands with **further key appointments (4 RS URFs and 1 STFC ERF since 2014)**.

...hold international leadership roles, e.g. the **€4M ITN "SAGEX"**, involving 14 world-renowned institutions and 7 industrial partners.

...**expand into new areas**: double copy, gravitational waves, phenomenology, pure mathematics.

...forge **interdisciplinary links** to drive further discovery in condensed matter, linguistics, data science and machine learning.

Particle Physics Research Centre (PPRC)

The **PPRC** probes core challenges of fundamental physics through multidisciplinary collaborative research, the development of novel detectors, scientific computing, and participation in renowned international experiments. PPRC hosts two groups: *ATLAS* and *Neutrino Physics*.

Academic staff: 8 FTE	PDRAs: 25 (53.8 years)
PhDs completed: 30	Income-in-kind: £36.6M
Articles: ⁵ 121	Citations: 9843
<u>Membership</u> 2P, 3R, 1SL, 1L, 1 fellow (proleptic)	
Professors:	Bevan ⁴ (Director), Hobson (Head of School)
Readers:	Bona ⁴ , Hays, Rizvi
Senior Lecturers:	Blumenschein
Lecturers:	Zenz
Fellowship holders:	Cremonesi (UKRI FLF, L)
2 physicist-programmers, 2 computing cluster-managers, 2 technical engineers, 1 senior research fellow, 1 applied physicist	
Research grant awards 2014–2020: £11.6M	

The ATLAS group (Bevan, Blumenschein, Bona, Hays, Rizvi, Zenz), draws on expertise in collider physics, machine learning and data science to study Higgs boson physics, test the Standard Model, and search for new physics. Our academics have been appointed to top-level convenorship roles (Bona, Blumenschein) and sub-group convenor positions (Bevan, Bona, Rizvi).

The Neutrino Physics group (Bevan, Cremonesi, Hays, Di Lodovico, Katori, Wilson⁶) studies one of the most elusive fundamental particles, focusing on neutrino oscillations (T2K), neutrino-less double-beta decay (SNO+), tests of Lorentz symmetry (Ice Cube), CP violation (NOvA and the forthcoming Hyper-Kamiokande and DUNE experiments). After graduating from PPRC in 2015, Cremonesi returned as the holder of a UKRI FLF, strengthening the group with 2 PDRA positions. One more permanent post is already planned for 2021.

Scientific computing and detector development: PPRC plays a leading role in scientific computing, hosting one of the five major GridPP Tier-2 sites, holding membership of the GridPP Project Management Board (Hays), and chairing the Resource, Scrutiny and Allocation Panel of the £16M STFC IRIS Project (Hays). Detector development is a core activity for instrument design and construction for our fundamental science programme. Increased multidisciplinary collaboration on new technology development has led to a new detector development sub-group, inaugurated in October 2020 (Bevan, Hays, Hobson, Kreouzis-CCMMP, Zenz). As a result of the Centre's experience in machine learning, PPRC has partnered with the National Crime Agency (Rizvi), and received a GCRF grant for air quality forecasting in Mexico City (Bona). These activities tie into postgraduate training run by the Data Intensive Science Centre and Data-Centric Engineering Centres for Doctoral Training (DISCnet CDT and DCE-CDT).

⁵ Including only those with a key contribution from PPRC academics, out of ~1850.

⁶ Di Lodovico, Katori and Wilson left in 2019.

Research strategy

The key aims of PPRC's research strategy are to...

...hire **talented, diverse early-career researchers**. Since 2014 we have hired 3 early-career academics including 1 FLF.

...build upon our **participation and leadership in international experiments** (e.g. ATLAS, DUNE and NOvA) to pursue fundamental science discovery.

...seek increased **industrial and multidisciplinary collaboration** in the areas of detector development and scientific computing.

... herald an era of **precision Higgs physics** with the ATLAS upgrade, and **expand our neutrino group**.

2. People

2.1 School recruitment policy

Our recruitment strategy focuses on **renewal and rejuvenation**, as underpinned by our Research Strategy (see [Section 1.2](#)). Thanks to our vibrant research environment and reputation, we have been successful in attracting internationally renowned researchers: in the REF period, 14 early-career researchers joined our School with an advanced fellowship, 13 of whom with proleptic appointments⁷. Furthermore, five existing staff members held fellowships⁸, one academic joined with a senior fellowship, **for a total of 22 distinguished fellowships** (see [Table 1](#)). Our retention of proleptic fellows is excellent, with only one moving to a senior position in their home country.

ERC Starting Grant	<i>Drew</i> (2012-17), <i>Wilson</i> (2011-2017; now Reader at KCL), <i>Di Lodovico</i> (2009-14; now Professor at KCL), <i>Baker</i> (2021-2026), <i>Bull</i> (2021-2025)
Royal Academy of Engineering	<u>Mol</u> (2016-2021; holds UKRI FLF as of 2020, so RAEng fellowship has been terminated).
Royal Society	Dorothy Hodgkin: <u>Haworth</u> (2019-2024); Brian Mercer: Homewood (2015-2018; now retired); URF: <u>Mulryne</u> (2014-2023, 0.8FTE); <u>Buican</u> (2016-2023); <u>Baker</u> (2019-2023); <u>Paardekooper</u> (2013-2021); <u>Monteiro</u> (2017-2021); <u>Wen</u> (2018-2022); <u>Papageorgakis</u> (2013- 2021)
UKRI Future Leaders	<i>Pourtsidou</i> (2019-2023), <i>Mol</i> (2020-2023), <i>Cremonesi</i> (2020-2024)
STFC Ernest Rutherford	<u>Jimenez-Serra</u> (2016-2020, now at the Instituto Nacional de Técnica Aeroespacial, Madrid); <u>Chen</u> (2017-2021); <u>Vegh</u> (2017-2022)
Winton Exoplanet	<u>Gillen</u> (2018-21)

Table 1. Independent fellowships during the REF period. Underlined names denote proleptic appointments, while names in italic denote awards received whilst employed at QMUL.

⁷ Cremonesi was awarded a fellowship that starts after the census date before joining QMUL.

⁸ In addition, Baker and Bull received fellowships within this REF period that begin early 2021.

Unit-level environment template (REF5b)

We have also recruited substantially; despite some staff retiring (8 headcount or 5.9 FTE) or moving to other UK/European positions (10 headcount or 9.8 FTE), the size of the School has remained approximately stable, with 48.8 FTE in REF2014 (24 submitted to UoA9 and 10 to UoA13b) and 48 FTE on REF2021 census date. New appointments comprise high-calibre mid-career (Blumenschein, Clarkson, Shigemori, White) and senior staff (Green FRS, Hobson, Perry), in addition to the independent fellows listed above. We proudly note that Cremonesi and Papageorgakis obtained their PhDs at our School, fulfilling QMUL's goal of **developing our staff and students to become world leaders in research and innovation**.

2.2 Staff development

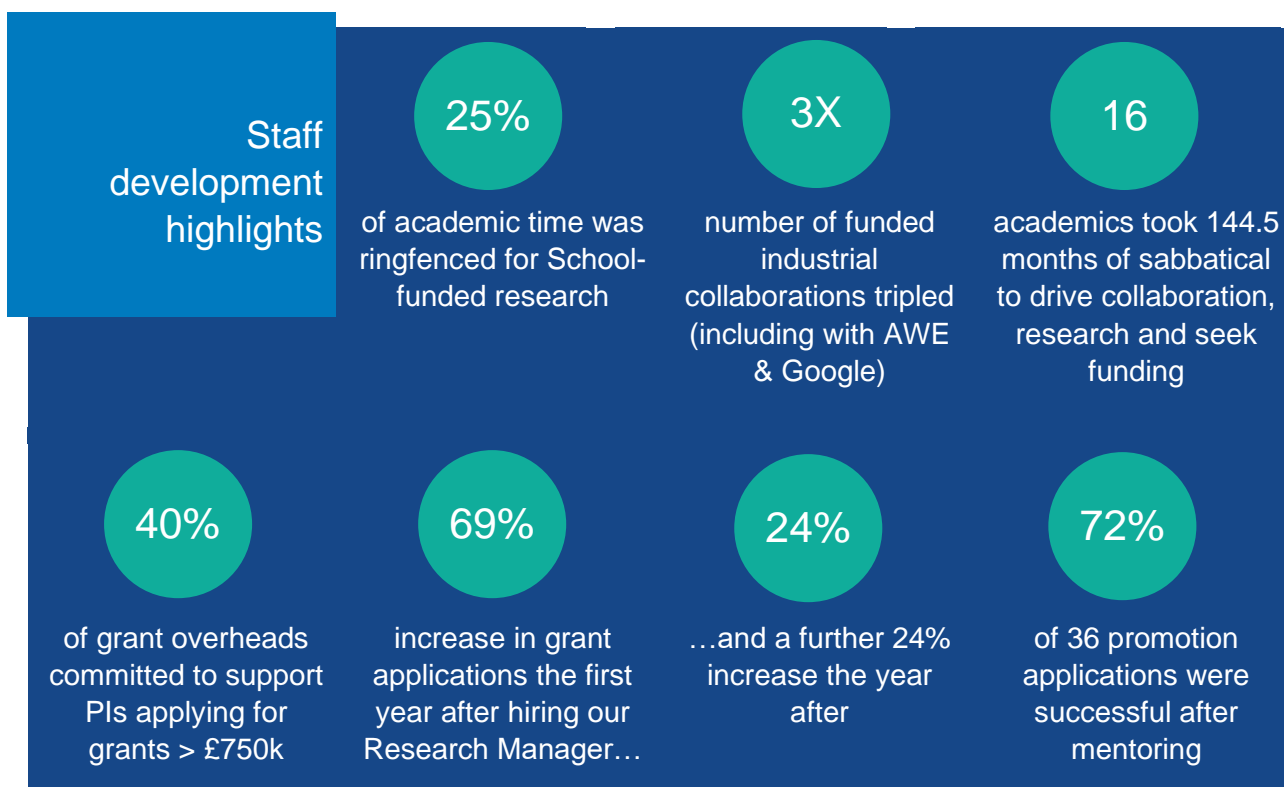
We prioritise the personal and career development of our staff, fully implementing the *Concordat to Support the Career Development of Researchers*:

*Development and support of our **early-career staff***

All early-career staff attend a professional development course, and receive a Postgraduate Certificate in Academic Practice or Fellowship of the Higher Education Academy upon completion. Teaching is gradually increased after appointment, with half loads during the first two years, and PhD studentship funding is prioritised (typically 2 PhD students in the first 3 years). Senior academics offer grant application advice, mentors offer guidance to help individuals integrate into the School's ethos, and we run formal and informal staff mentoring schemes, including for promotion applications.

*Development and support of **staff at all career stages***

Alongside general institutional policies – such as appraisals, discussed in (REF5a, Section 3), we have a number of policies specifically tailored to support staff as they progress through their careers. Highlights include:



Unit-level environment template (REF5b)

In addition, we offer various forms of critical support:

Grant-related support

- Through our workload allocation model, we reward staff for carrying out research, PhD supervision, achieving impact, and demonstrating leadership.
- Grant holders receive 'Research Enabling Funds' (10% of overheads, up to 40% for grants > £750k), enabling them to enhance their research and collaborations.
- Applicants shortlisted for fellowships are offered multiple rounds of mock interviews with panels including members of the School and, when appropriate, related Schools.
- Our research manager coordinates grant preparation and review and updates staff with grant opportunities.

Career development

- We support promotion applications via annual faculty-led workshops and guidance from appraisers and mentors, with strong success highlighted above. All fellows have reached the end of their fellowships as Senior Lecturers or Readers, demonstrating the effectiveness of our staff development policies. Overall, 4 academics were promoted to Professor, 8 to Reader and 14 to Senior Lecturer.
- We clearly communicate future employment prospects to staff on fixed-term contracts, and have a clear policy for sabbatical leave (including for fixed-term and part-time staff) planned to develop international collaborations, impact activity, new lines of research and associated funding. 16 academics took sabbatical leave during the REF period.
- Senior academics are encouraged to take on senior university positions (e.g. Spence was Vice-Principal Research for 2013-2019), complete external AdvanceHE courses in leadership, and attend QMUL's 'High-Potential Leadership Programme'. This has been attended by mid-career staff who have since held faculty leadership positions (e.g. Bevan, Deputy Director of the IADS; Drew, Director of the MRI; Rizvi, Deputy Dean for Research).

Industry-facing research

- Our Director of Impact assists with designing projects, writing grants, collecting evidence, drafting case-studies, and liaising with university-wide impact services. We also help staff in applying for EPSRC and STFC Impact Acceleration funds and advise on commercialisation and collaboration.
- By appointing a Director of Industrial Liaison (Bevan), we have almost tripled the number of funded collaborations in the School (29 new, including the AWE, National Crime Agency and Google), and driven a year-on-year increase in Impact Acceleration funding via industry-facing networking events organised in the School (with 5 in 2019).

2.3 PhD students

2.3.1 Recruitment

We have **significantly increased** the number of PhD students graduating per annum – from 10.6 in REF2014 to 17.2. Of the 133 students recruited in this REF period, 38 have been supported by

Unit-level environment template (REF5b)

overseas government funding from China, Mexico, Pakistan, Saudi Arabia, Turkey, or UAE. Our funding streams (see *Figure 2*) have increased and diversified, including the STFC, EU Marie Skłodowska-Curie ITN, Royal Society and QMUL Principal's Studentships, and we have secured external funding from e.g. the National Decommissioning Authority, AWE, and facilities such as Diamond and ISIS. Our funding sources have increased in number from 14 to 21, largely due to international studentships. We recruit PhD students globally in-line with QMUL and School EDI policy⁹, and have 21 nationalities in our cohort.

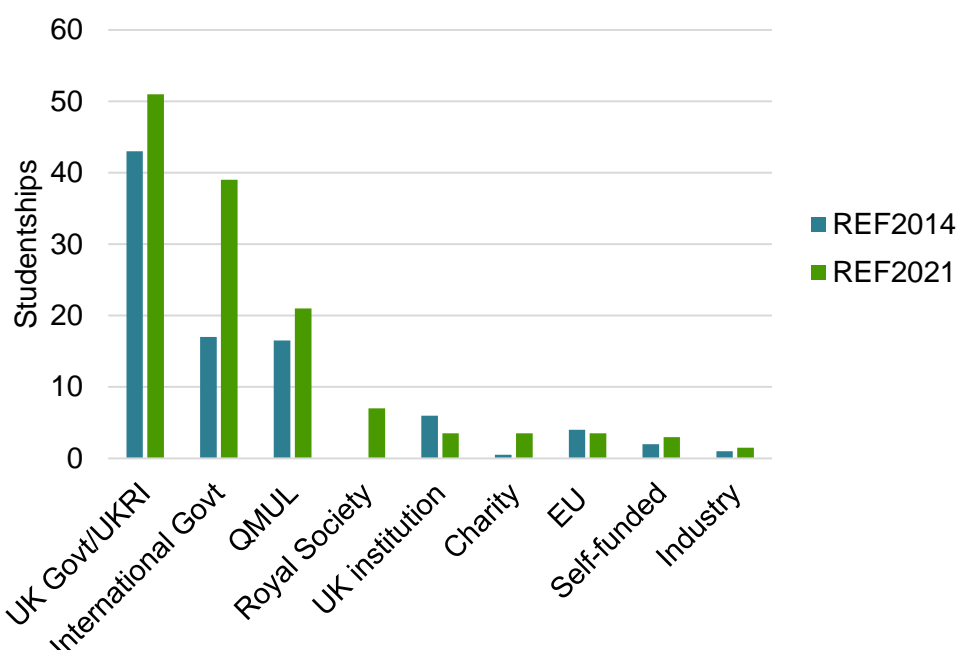


Figure 2. PGR funding sources.

2.3.2 Training

We offer a wide range of diverse training opportunities for our students:

- **Lectures and courses:** Provided by our research centres, the QMUL Doctoral College and academic development units (e.g. bespoke courses and graduate interdepartmental training from the MRI), intercollegiate partners (e.g. advanced physics graduate lectures from the University of London), SEPnet/GRADnet, and other European universities. Such courses deliver up to 160 hours of specialist training in the first year and up to 60 in subsequent years.
- **Graduate networks:** Comprehensive training is provided by the CDT DISCnet (AU and PPRC), ITN SAGEX (CRST) and GRADnet (CRST and PPRC), see [Section 4.1.3](#) for details.
- **Summer schools:** We regularly organise and host international summer schools such as the Mandelstam Theoretical Physics School in Durban, South Africa (2019 and 2020; Ramgoolam), the national STFC Data Science Summer School in Sussex, UK (2019; Rizvi), and the 50th STFC British Universities Summer School in Theoretical Elementary Particle Physics (BUSSTEPP), hosted at QMUL in early 2021 (Russo).

⁹ For EDI aspects in recruitment at all levels see [Section 2.6](#).

Unit-level environment template (REF5b)

- **Skills training:** We consistently rank as one of the top three institutes (of 15) for engagement in GRADnet bespoke transferrable skills training (in areas including software engineering, networking, entrepreneurship and business skills). Students also engage in DISCnet training, with feedback confirming that this is well-delivered and highly research-relevant.
- **Secondments:** Students are encouraged to take secondments at other institutions or in industry, and supervisors proactively help to secure these. Some PhD programmes (e.g. SAGEX) have secondments built in.

Our PhD students are also supported by student-led events, from annual poster competitions judged by leading industry representatives to GRADnet conferences, and enjoy a vibrant research environment as a result of:

Seminars and journal clubs organised by each Research Centre, including student-led seminars and series open only to students.

Weekly seminars run by the [MRI](#), with speakers ranging from PhD students to internationally leading scientists. Our students also benefit from our membership of major networks such as the [London Triangle](#) and the [Thomas Young Centre](#).

Two **School colloquia** per term, plus **regular symposia on topical cross-boundary subjects** with prominent researchers – including Nobel Prize winners – as plenary speakers. Academics and students meet and interact, forging connections between Centres.

The **PhD Forum**, a student-run organisation financially supported by the School, where PhD students voice their opinion on all matters relevant to life in the School.

The training our students receive makes them eminently employable – recent destinations include ASI Data Science, Barclays, CERN, DeepMind, HSBC, Oak Ridge National Laboratory, and VividQ.

2.3.3 Academic and pastoral support

We ensure that our PhD students are fully supported: each student has a primary and secondary supervisor guiding their development; each Centre has a PhD Tutor independently monitoring progress to address issues as they arise; and all new academics must attend a PhD Supervision workshop, with training refreshed every two years to maintain best practice. We have also produced a bespoke postgraduate handbook providing general guidance for new PhD students.

As a result of our efforts, we have **substantially increased our four-year submission rate – to 91%** for the last cohort in this REF. **Progression from first to second year is now 98%. Student satisfaction is closely monitored and has risen considerably**, e.g. by 29% for overall experience and 19% for research culture.

Unit-level environment template (REF5b)

Our Graduate Degrees Committee (GDC) oversees all aspects of PhD studies, ensuring that high-quality supervision and student experience is maintained. It comprises PhD Tutors, the Director of Graduate Studies (Chair and Research Committee member) and a dedicated administrator. Supervisors and students prepare biannual joint progress reports, including a reflective self-assessment and a training plan monitored by the GDC. All students take a formal annual progression, and an annual final-year cohort day has been introduced in which the expectations of students' work and progress are clearly laid out (including the processes for thesis writing and submission, and all relevant deadlines and timescales). As part of their career development, students are offered paid training in teaching, demonstrating and tutoring. Finally, a dedicated student support officer is available to provide pastoral support and signpost to relevant support services when necessary.

2.4 Postdoctoral research assistants

Since REF2014, **86 externally funded PDRAs (142.8 years) have been appointed from a diverse set of funders** (such as the EPSRC, STFC and EU), and 7 have obtained permanent appointments at leading institutions. PDRAs are encouraged to work with other researchers, to give presentations to foster collaborations, to engage in outreach, and to enjoy our wide selection of staff training courses. They follow QMUL's Probation and Appraisal schemes, with informal meetings taking place to develop their Career Development Plan, monitor progress and identify training needs. In addition to our formal arrangements, we run a mentorship programme where all staff are encouraged to choose a mentor (based either inside or outside of the School). PDRAs are funded to visit national and international institutions, workshops and conferences to present their research and open up future career opportunities.

2.5 Professional services

Since REF2014, the School has invested heavily in professional services: we have 9.8 FTE staff supporting research, costing approximately £0.6M annually, and introduced the role of Research Manager in 2017. Our professional staff are encouraged to not only engage with their day-to-day roles, but to also use their skills to embed themselves in our research community. Many professional staff are also active research contributors: Physicist Programmer Owen, for example, is a named author on two recent publications; our Outreach Officer is an active researcher on space weather and the Earth's magnetosphere; he collaborates with academics as part of the [*Physics Research in Schools Environment \(PRiSE\) project*](#) – a project that engages school students with hands-on research – and was nominated for a Times Higher Education Award in 2019. By minimising the academic-professional services boundary, we have developed a culture in which **research forms the bedrock of all our activities**.

2.6 Equality, diversity and inclusion (EDI)

Our dedicated EDI committee (established in this REF period) brings together members from all research groups and career stages, from undergraduate students to the Head of School, via termly meetings to develop best practice and spearhead cultural change within the School. The School has twice been named a 'Juno Champion' by the Institute of Physics (the highest level of the award – first in 2015, renewed in 2019), and has Athena SWAN 'Silver' status (first awarded in 2015, and renewed in May 2020).

EDI highlights

The number of newly recruited female academics has **more than doubled** compared to REF2014. **24%** and **35%** of our PhD students and postdocs, respectively, were female.

The ratio of successful mentored promotion applications from female academics was higher than for males (**86% vs. 69%**).

Two academics transitioned to **0.8 FTE** to support their childcare responsibilities, and were later promoted.

All women employed in the School for 5+ years have been promoted at least once. Of the two academics to progress from lecturer to professor within **10 years**, one was female.

48% of academic staff appointed were not born in the UK.

To ensure that this positive trajectory continues, we have a number of EDI policies in place:

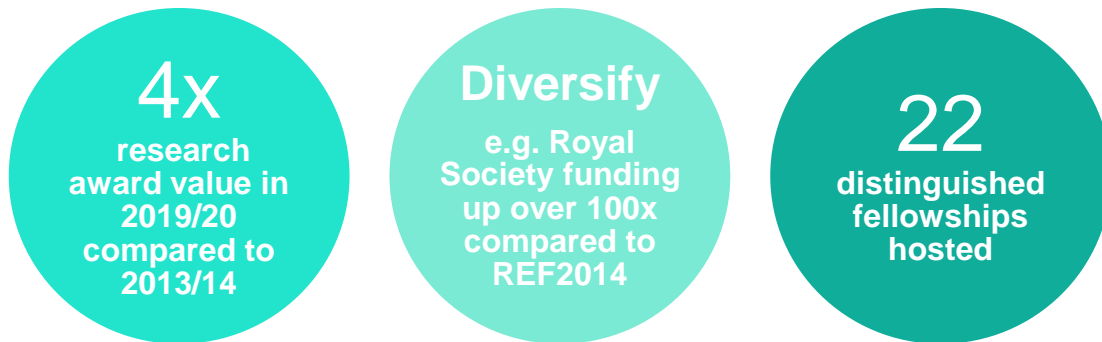
- Positive action is applied in recruiting at all levels from PhD students to academics, and all job adverts are checked for gender-specific language. Shortlists are monitored for gender/race imbalances.
- ‘Unconscious Bias’ training is compulsory for all staff. Further training courses cover aspects of recruitment, appraisals and mentoring.
- A ‘Parental Leave Plus’ policy (one of two Schools at QMUL) providing all academics with PDRA support while on parental/adoption leave.
- Support for staff with disabilities, and dedicated disability, gender, BAME, LGBTQ+, and international staff and student ‘Champions’ (recognised for their leadership via our workload allocation model; see [Section 2.2](#)).
- Staff/students with caring responsibilities can request formal flexible/part-time arrangements. Staff returning from long-term absence are given a reduced, non-teaching workload, and priority for PhD student, conference and travel requests.
- All seminars/meetings are scheduled within core hours.
- EDI representatives sit in on Faculty promotions panels. Career breaks/part-time arrangements are taken into account.
- The School provides funding/time for attending internal/external training courses. Where external exams are taken as part of gaining a qualification, study leave can be requested.
- Staff have access to ‘Mindfulness and Wellbeing’ training, four mental-health first aiders, discounted QMUL-gym membership and an employee-assistance programme for advice, referrals or counselling.

Crucially, **we have embedded the EDI programme in the management structure**, with the Terms of Reference for all committees in the School including EDI roles and responsibilities.

3. Income, infrastructure and facilities

3.1 Income

A core strategic aim of QMUL is to “significantly increase external research funding from multiple national and international sources” (see REF5a, Section 2). Incorporating this in our [Research Strategy](#), since REF2014 the School has considerably increased and diversified grant income, from £18.5M (£15.9M in the part of the School submitted to UoA9 in REF2014) to £29.8M.



As shown in *Figure 3*, annual research income has increased from **£3.6M** at the beginning of REF2014 (£3.1M in the part of the School submitted to UoA9) to **£5.9M** (2019/20). This increase is especially significant given that the number of academic staff is almost unchanged since REF2014, the STFC settlement has been flat cash, and that two of the four groups (AU and CRST) pursue predominantly blue-sky theoretical research.

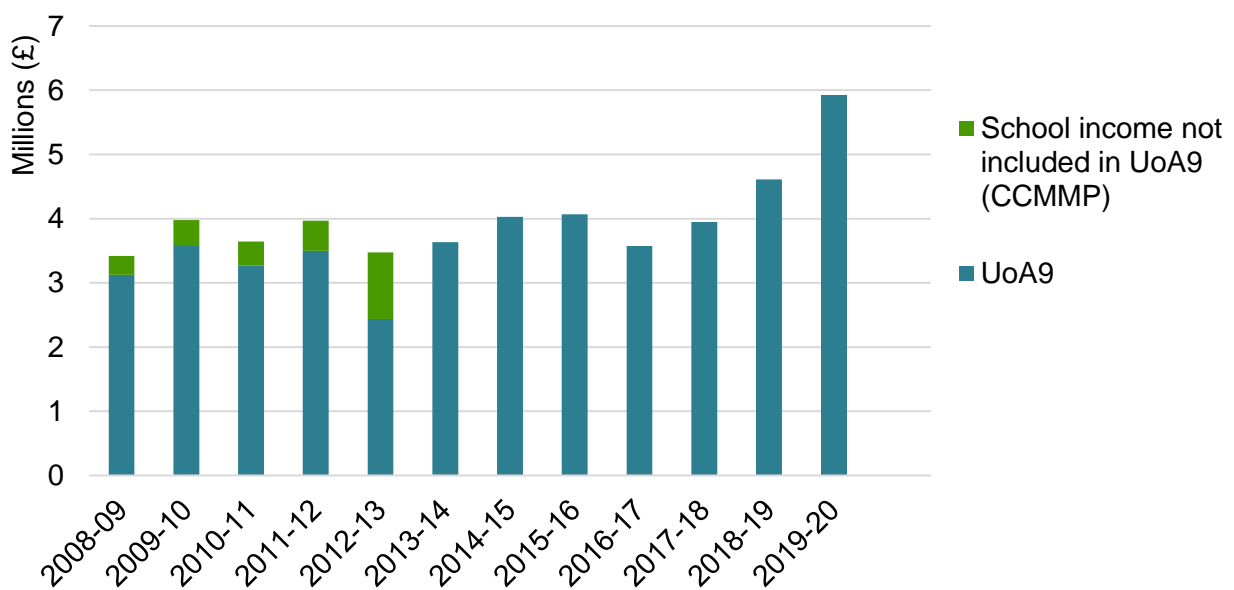


Figure 3. Research income, excluding in-kind.

Unit-level environment template (REF5b)

The success of our grant diversification strategy is demonstrated in *Figure 4*. **The value of awards has quintupled from £2.4M in 2013/14 to £12.7M in 2019/20**; this has been achieved by doubling the number of distinct PIs and increasing the diversity of grant-awarding bodies, e.g. non-STFC funding has risen from 27% to 45% between REF periods (see *Figure 1*). Specifically, **we have dramatically increased UKRI** (including research councils other than EPSRC and STFC) **and Royal Society funding**: the former increased from ~£21.4k p.a. to ~£568k p.a.; the latter from ~£7k p.a. to ~£917k p.a. We also highlight our leadership role in two major, large consortia grants: the EU ITN [SAGEX](#) and the EPSRC-funded [DataCentric Engineering Centre for Doctoral Training](#) – further discussed in [Section 4.1.3](#).

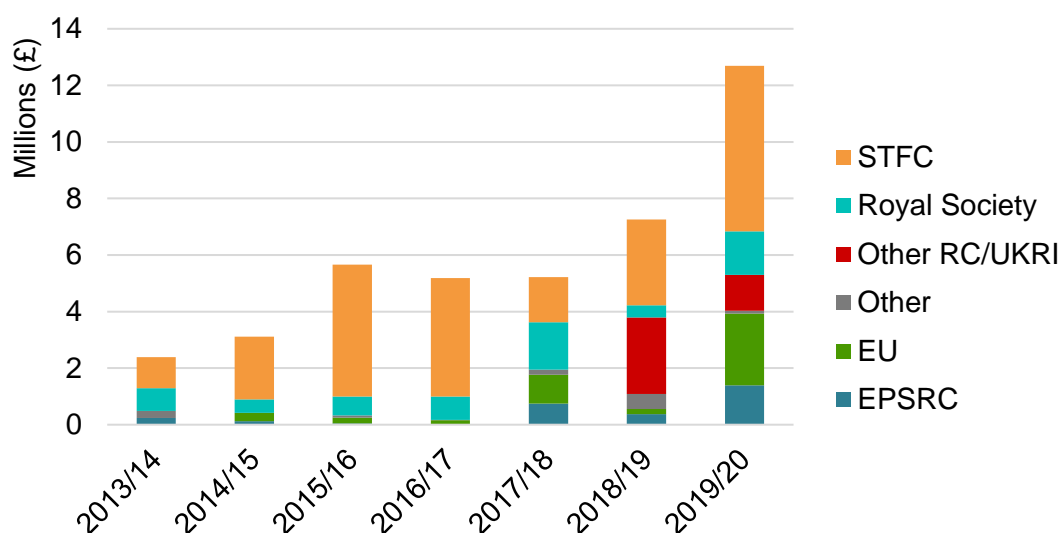


Figure 4. Research grant value by award date. Note a significant increase in awards and funding sources.

3.2 Income-in-kind

Our in-kind income – from research council-funded facilities – is two orders of magnitude larger than in REF2014¹⁰, as reported in *Table 2*.

Research group	Value	Description
AU	£1M	Value of time on telescopes (ALMA, Cluster, ESO) reported by UKRI.
PPRC	£35M	CERN subscription, maintenance and operations for our CERN and T2K activities.
CCMMP	£8.3M	Value of beam time on neutron and muon sources and synchrotrons, reported by STFC.
AU and CCMMP	£1.3M	Value of computation time on national facilities (Archer , Athena , PRACE , Thomas). Based on known CPU-hours per user, with the cost of each CPU-hour provided by the facility operators. Cost of time on DIRAC provided directly by STFC.
Total	£45.6M	

Table 2. Income-in-kind from access to research council supported facilities.

¹⁰ Also taking into account incorrect reporting for 2012-13.

Unit-level environment template (REF5b)

We have been co-investigators on two strategic EPSRC infrastructure grants worth a total of £7.2M (MMM: EP/P020194/1, MidPlus: EP/P020232/1), which were used to procure some of the facilities shown in *Table 2*. We are also active users of national facilities abroad, including the Institut Laue-Langevin (France; 14 days, £522k), PSI (Switzerland, 32 days) and ANSTO (Australia; 10 days, £35k).

Additionally, PPRC has received notable in-kind contributions ranging from facility access to research support to studentships:

£1.2M of in-kind support for an EPSRC doctoral training centre (DCE-CDT), with industrial contributions to research support (staff costs, process adaptations)

Contributions relating to activity on Fermilab's **Deep Underground Neutrino Experiment** (DUNE). The School benefits from these via access to the UK STFC's Rutherford Appleton Laboratory, the Fermilab and SURF facilities in the US, and Canada's SNOLab

We have also received non-UKRI in-kind facility access contributions – including site usage at AWE Aldermaston – and PhD studentships from other sources such as QMUL's [Life Sciences Institute](#) (bringing together particle physics data-science algorithms and cancer proteomics) and the National Decommissioning Authority.

3.3 Infrastructure and facilities

Our two-year £12M refurbishment of the School building was completed in 2015. The building was stripped back to its steel and concrete supports and entirely rebuilt from within, with the inclusion of new offices, interaction spaces and laboratories with state-of-the-art equipment. This represents almost double the investment of the REF2014 period (£6.5M). £3M went into refurbishing our laboratories.

3.3.1 Research institutes

QMUL's cross-faculty research institutes have attracted significant internal investment in recent years – and the School has been an integral part of several of these.

Institute for Applied Data Science (IADS, Deputy Director: Bevan)

Established in 2018, the IADS coordinates world-class data science and AI research across QMUL, and has empowered our School with both £2.7M of external funding and a multidisciplinary network of collaborators. IADS-enabled grants include an EPSRC DCE-CDT (Rizvi), support for organisation of national meetings on data science for the STFC community (Bevan), and GCRF-funded research on air quality (Bona).

Materials Research Institute (MRI, Director: Drew)

The director of the MRI, an interdisciplinary institute established in 2013, has been based in our School for 6.5 of its seven-year lifetime (Dove 2013–2016; Gillin 2016–2018; Drew 2018–present).

The School was instrumental in setting up the MRI, which connects the School's CCMMP to QMUL's Schools of Electronic Engineering and Computer Science, Engineering and Materials Science, Biological and Chemical Sciences, and Dentistry to foster cross-cutting research collaborations between faculties, schools, industry and academia. All CCMMP group members are also members of the MRI. Overall, MRI fellows alone have generated approximately **£2.3M in research awards**, including a Royal Academy of Engineering Fellowship and a Future Leaders Fellowship (Mol, total award value over £1.5M), and forged wider collaborations including the

Unit-level environment template (REF5b)

EPSRC-funded (£2M) CAM-IES network with Cambridge, UCL and Newcastle (MRI fellows Schroeder and Nielsen; CCMMP Gillin). In total, **MRI collaborations have brought in £15M in research grants.**

The CCMMP and MRI are members of the EPSRC Tier-2 Hub in Molecular and Materials Modelling (recently renewed with £4.5M of EPSRC funding) and Tier-2 Hub Midlands Plus (renewed with EPSRC funding), and collaborate closely with the multi-institutional [Thomas Young Centre](#) (TYC; the London Centre for the Theory and Simulation of Materials). Since 2014, a total of 14 high-profile TYC soirées have been hosted at the MRI.

3.3.2 Facilities

PPRC hosts **one of 5 major UK Tier-2 clusters** (6000 cores and 9 PB storage), operating scientific computing infrastructure on behalf of GridPP and the STFC IRIS project. Attracting around £3.5M external investment in capital and people over the REF period, these facilities enable international computation for CERN's Large Hadron Collider and beyond, across the diverse areas of particle physics, astrophysics, cosmology, nuclear physics and bioinformatics. Co-hosting infrastructure with other groups from across the institution enables PPRC to provide in-kind support to smaller groups without dedicated support posts.

The School used its in-house cleanroom and nitrogen glovebox facilities to invent and characterise a new organic semiconductor-based neutron detection device, with support from the STFC and its Impact Accelerator Award, 1.5 PhD studentships funded by AWE, summer internship funding by NuSec, and QMUL seed funding. This involved collaboration between multi-disciplinary teams in CCMMP and PPRC, and resulted in the filing of an international patent.

In addition to open-access and shared laboratories within the schools contributing to the MRI, we operate several world-class laboratories, including those at the CCMMP and PPRC.

The CCMMP hosts one clean room (60m², class 10,000) and three laboratories (one 120m² general purpose, one 60m² wet chemistry, one 60m² laser). CCMMP and PPRC share a class-100 clean room (35m²).

The PPRC hosts one clean room (35m², class 10,000) and four general purpose laboratories (75m² in total), which collectively include over £1M of equipment (including an automatic wedge bonder, optical and mechanical coordinate measuring machines, a semiautomatic probe station, and a wire bond and micro material test system for semiconductor and instrument construction). The School also has tools for equipment construction – especially equipment relating to the PPRC particle accelerator detector building and testing programme – in research workshops totalling 145m² in size. As part of the recent facility overhaul, which saw £12M investment into the School, the MRI has overseen the construction of new research laboratories and acquisition of core research equipment. Staff now have access to state-of-the-art instrumentation, including:

£535k	£400k	£180k	£204k	£160k
XPS	Cluster thin-film molecular beam deposition system	High-throughput powder X-ray diffraction system	Scanning Raman microscope	Ultrasonic wedge bonder

4. Collaboration and contribution to the research base, economy and society**4.1 Research collaborations, networks and partnerships**4.1.1 Approach to developing research collaborations and networks

Our research culture aims to **empower a diverse range of partners to perform novel and impactful collaborative research**. To this end, QMUL has made significant investments in regional and national partnerships including:

1. [SEPnet](#) – South-East Physics Network of ten regional universities supported by a ten-year HEFCE grant of £15.2m (2008-2018) and ongoing institutional investment. It provides the GRADnet graduate school and was instrumental in the creation of the **DISCnet CDT** (see [Section 4.1.3](#)).
2. [NExT](#) Institute has led to a successful joint PhD programme with U. of Southampton graduating 6 PhDs since 2014.
3. [Alan Turing Institute](#) – the School hosts two fellows applying data science and AI to new research problems (Bevan, Rizvi).
4. [IPPP](#) – Award of three associateships to collaborate with phenomenologists at Durham's IPPP (Bevan, Di Lodovico, Rizvi).

The university also provides funding – up to £2k – for academics wishing to deepen collaborations with targeted universities. Examples of this include Rizvi, whose collaboration with the University of São Paulo, Brazil, resulted in two joint publications and an agreement allowing QMUL to access bilateral Brazilian funding; and Bona's collaboration with the Instituto Politécnico Nacional in Mexico, which resulted in a follow-up GCRF-funded PDRA position in our School. Funds are also available for PhD students (£2k via Postgraduate Research Funds) wishing to work with world-leading experts, access unique facilities, and repatriate skills to the UK (e.g. collaboration with Super-Kamiokande); academics are encouraged to host international conferences and provided with up to £2k of financial support (e.g. Rizvi QCD@LHC 2015); and Research Enabling Funds (see [Section 2.2](#)) can be used flexibly to support collaboration.

4.1.2 Collaborations and partnerships

International partnerships are a key strength of our research. We successfully attract outstanding external collaborators – and benefit from a bilateral flow of expertise and wider access to world-leading facilities as a result.

AU

The AU has brought together, for the first time, leading contributors to major cosmological next-generation surveys including ESA's Euclid mission, LISA, HERA, the LSST and the SKA. Academics hold leadership positions in the Working Groups for each of these missions (Baker, Clarkson, Pourtsidou), with Pourtsidou being Coordinator of the InterScience Taskforce for nonlinearities in Euclid, and Bull serving on the HERA Telescope's International Executive Board. Successful collaborations have developed from these activities, including a QMUL PDRA on the HERA Telescope funded by the University of California, Berkeley. The SKA project has intensified research with the University of Western Cape (South Africa), resulting in three long-standing visiting positions (Bull, Clarkson, Pourtsidou). The AU leads work-packages for the PLATO mission (Nelson, Paardekooper) and Gillen is a member of the NGTS consortium, with strong collaborative

Unit-level environment template (REF5b)

links with members of the TESS mission. In 2014, the AU established the Perren Visiting Professor programme, funding long-term visits by leading astronomers: Bale (Berkeley); Nicholson (Cornell); Sorriso-Valvo (Nanotec/CNR and University of Calabria); and Sussman (UNAM, Mexico).

CCMMP

CCMMP is an active member of the [Thomas Young Centre](#) – with co-investigators on two national computing facilities: Midplus and MMM – and is a leading group in the use of the large-scale ISIS and Diamond facilities, with Dove, Drew, Phillips, Sapelkin and Trachenko using neutron, X-ray synchrotron and muon beamlines. to study a variety of materials. Dove, Drew, and Sapelkin have developed instruments at ISIS and Diamond. In 2012, a Sino-British Materials Research Institute with Sichuan University (SCU) was established under the directorship of Gillin, with Dove, Drew, Gillin and Kreouzis holding visiting professorships. This collaboration has spanned disciplines and QMUL Centres, with CRST contributing to teaching at SCU (Wecht, ex-QMUL) and PPRC participating in joint research on radiation detectors (Bevan). CCMMP has attracted significant International Exchange awards (Dennis, Drew, Misquitta, Phillips, Sapelkin) funded by the GCRF, Royal Society, CNRS-France, and Natural Science Foundation of China.

CRST

CRST has longstanding research links with Witwatersrand University (South Africa), where Ramgoolam holds a funded six-year visiting professorship. A resulting joint post-doctoral programme has created extended QMUL secondments for four Witwatersrand PDRAs. Strong collaborations exist with the University of Kyoto (resulting in over 20 joint papers and a memorandum of understanding for further collaborations), Nikhef (Dutch National Institute for Subatomic Physics), Humboldt University Berlin (resulting in the joint SAGEX grant), and the University of Cambridge. CRST is a founding member of the [London Triangle](#), the world's largest string theory network. Its shared seminar programme has over 40 academics and attracts world-leaders to speak at its meetings. The network provides the basis for the STFC-funded Fundamental Physics UK Virtual Network, which commenced in October 2020. CRST was also a partner of the COST Action '[The String Theory Universe](#)'.

PPRC

PPRC is strongly engaged in field-leading large-scale experiments, as reflected by leadership positions in the top-level Working Groups of ATLAS (convenorships: Bona, Blumenschein), ANITA, NOvA and DUNE (Cremonesi), and Hyper-Kamiokande (International Spokesperson: Di Lodovico). The group leads highly cited phenomenological collaborations including UTFIT, HFLAV (Bona), BlackMax and HERAPDF (Rizvi), and collaborates with the RAL Particle Physics and Technology Divisions and US institutes including Yale and UC Berkeley on the ATLAS upgrade.

4.1.3 Doctoral training partnerships

The School has a longstanding history of collaborative PhD training, as shown below, and was a partner in the EU-funded ITN [GATIS+](#).

SAGEX	Led by QMUL, SAGEX (Scattering Amplitudes: from Geometry to EXperiment – PI: Travaglini, €4M) is an EU-funded ITN of 7 industrial partners and 14 leading international institutions across Europe (UK, Austria, Denmark, France, Germany, Ireland and Switzerland), the US and Canada. It is the first such consortium to train students in scattering amplitude research, and provides industry secondments with partners including Wolfram, Maplesoft, Danske Bank and Mærsk.
DCE-CDT	Led by QMUL, the DCE-CDT (Data-Centric Engineering Centre for Doctoral Training – PI: Rizvi, £1.6m) will offer a multi-disciplinary programme of training co-delivered with industry partners. The highly innovative CDT aims to upskill those from non-academic backgrounds with doctoral-level skills in workplace-based research across engineering, computer science and physics. Highly talented individuals who left academia 3+ years ago are targeted, including employees of industry partners, and those who faced financial or self-confidence barriers to doctoral training.
DISCnet	DISCnet (Data Intensive SCience network) is the largest (£1.8M) STFC-funded CDT spanning five SEPnet institutes. It has trained 45 PhD students and 30 associate students in three cohorts, and offers industry, third- and public-sector placements transferring data science skills into the economy with 50 partners. QMUL has a substantial leadership role, with Rizvi as Director of Training and Skills. DISCnet was awarded the highest rating in STFC's mid-term review.
GRADnet	GRADnet is the largest graduate school in England, with a network of 200 regional employers offering applied research and knowledge exchange opportunities, and a diverse range of bespoke physics and transferrable skills training. Eleven collaborative events are held annually (25 days in total) including residential topical student-led conferences, winter and summer schools, free for all PhD students and PDRAs.

4.2 Contribution to the research base4.2.1 Peer review and editorships

Academics regularly referee for prestigious journals including *Nature*, *Science*, *Physical Review Letters*, *Journal of High Energy Physics*, with two holding journal editorships (Bevan, Clarkson).

4.2.2 Prizes and distinctions

Academics have been awarded international research prizes, including the EPSRC-CCP 2020 prize and top 10 Physics World Breakthroughs (Trachenko), the NASA Group Achievement Award 2018 (Murray), the Royal Astronomical Society Fowler Prize 2017 (Chen), the Humboldt foundation's Friedrich Wilhelm Bessel Research Award 2016 (Travaglini), the Georgia's Shota Rustaveli National Science Foundation Award 2016 (Tsiklauri), the Fulbright All-Disciplines Scholar Award 2015 (Baker), the Chinese Ministry of Education's Chiangjiang Distinguished Professor Award 2015 (Drew), the South African National Research Foundation's Internationally Acclaimed Researcher Award 2014 (Clarkson), and the Chinese Ministry of Education 'Talent 1000 Professor'

Unit-level environment template (REF5b)

Award 2014 (Drew and Gillin). Anglada-Escudé was named amongst the 100 most influential people (*Time*) and a top-10 scientist of 2016 (*Nature*).

4.2.3 Membership of funding panels and (inter)national advisory boards

During REF2021, 22 academics have sat on panels. Within STFC, these include three Experimental Oversight Committees (including as Chair – Bevan), the Fellowships Panel (Rizvi), three Advisory Panels (public engagement/Berman, astronomy/Sutherland, computing/Dove and Nelson), the Projects Peer Review Panel (Hays, Hobson), the Particle Physics Grants Panel (Travaglini), the Resource Allocation and Project Management Boards (Hays), and PPAP (Bevan from 10/2020). 7 academics are members of the EPSRC Peer Review College, and serve regularly on fellowships and standard grants mathematical and physical sciences panels. Green sits on the Royal Society's Dorothy Hodgkin Fellowship panel. Internationally, our research profile has resulted in panel membership at the European Commission, NASA, ANSTO, NIST, US Department of Energy, Swiss Science Foundation, German Research Foundation (DFG), South Africa's National Research Foundation, Research Council of Norway, CERN SPS/PS Experiments Committee, and Japan Atomic Energy Agency's Materials and Life Review Panel, as well as Vice-Presidency of the International Society of Muon Spectroscopists, Chairmanship of the ICTP-SAIFR in Sao Paolo (Brazil), the Meyer prize, and membership of the Dirac Medal and New Horizons Prize committees (Green, FRS), the Korean Institute for Basic Science evaluation Board (Berman), and the UK Space Agency JUICE Programme Management Board (Murray).

4.2.4 Other esteem

Academics have carried out 181 postgraduate defences and evaluated 198 proposals for international funding agencies including NASA (USA), NWO (NL), NSF (USA), DFG (Germany), NSERC (Canada) and the European Commission. Academics have held visiting professorships at institutions including the University of Cambridge, Harvard, Humboldt University Berlin, University of Rome Tor Vergata, Sorbonne University and CEMES-CNRS. Academics are members of learned societies, with Green being a Fellow of the Royal Society.

4.2.5 Conferences, visitors and workshops

Since 2014, academics have given over 170 plenary talks and colloquia at international conferences and workshops, including Amplitudes (Green 2020; Bianchi, Monteiro and Wen 2019; Brandhuber 2017; Green, Monteiro, Wen and White 2016; Travaglini 2015; Penante 2014), CKM 2018 (Bona), COSMO 2016 (Perry), COSMO 2019 and Euclid Consortium 2019 (Pourtsidou), ICHEP 2016 (Blumenschein), IGST (Travaglini, 2015), Solvay/Strings (Perry, 2019) and Strings (Buican and Perry 2016; Green, 2018).

The School received approximately 7400 days of collaborative visits and academic visitors for 6800 days, including **Nobel laureates Barish, Cronin, 't Hooft, Kobayashi and Penrose**.

Over the REF period, two conference series were created: IPA and NuPhys. We organised 25 (35) workshops, conferences and PhD schools at (outside) QMUL for a total of 66 (246) days, also with QMUL support. Examples include:

At QMUL:	100 years of GR (Clifton), Division on Dynamical Astronomy of the American Astronomical Society 2017 (Murray), European High Pressure Research meetings (Dunstan, Sapelkin, 2013), Interplay Between Particle and Astroparticle Physics, IPA2014 (2014, Bevan), LSST. Dark Energy Science Collaboration: Theory and Joint Probes working group hack meeting (Bull, 2018), NuPhys (2015/16/17, Di Lodovico), QCD@LHC (2015, Rizvi), SAGEX opening conference and Bern-Dixon-Kosower afternoon (Brandhuber and Travaglini, 2018/19), SKA-Euclid joint meeting (Bull, Clarkson and Pourtsidou, 2017).
Outside QMUL:	CECAM Flagship workshops (2016, Misquitta), Joint Abdus Salam ICTP and IAEA conference (2016, Trachenko), CERN-CKC TH Institute on Duality Symmetries (Berman, 2015), CERN LHCP 2019 (Bona), Division on Dynamical Astronomy of the American Astronomical Society (2019, Murray), Banff International Research Station (Berman, 2017), Corfu Institute (Berman, 2019), European Crystallographic Meeting and British Crystallography Association Spring Meeting (2016-2018 and 2020, Phillips), 50 Years of the Veneziano Model at GGI (Green and Russo, 2018), Kavli Institute for Theoretical Physics workshop on Scattering Amplitudes (Travaglini, 2017), Pohang Mathematics Institute (Berman, 2016), QCD@LHC 2016 (Rizvi), String Theory from a Worldsheet Perspective at GGI (Green and Russo, 2019), IPA 2016 and 2018 (Bevan, Bona and Hays).

4.3 Contributions to sustainability of the discipline

4.3.1 Interdisciplinary research

The interdisciplinarity of our research has increased since 2014 with the creation of the **MRI** and **IADS** (described in [Section 3.3.1](#)), which provide seminars, training and brainstorming events to remove barriers to networking, build industrial partnerships, and connect QMUL researchers to national bodies such as the Alan Turing and Faraday Institutes. As a result, the School has been able to apply advanced computer science and machine learning techniques to physics research (facilitated by, for instance, DISCnet students co-supervised by computer science academics).

4.3.2 Responsiveness to national and international priorities

The formation of the IADS is a direct response to the national data-science agenda, and tackles one of the Grand Challenges in the government's Industrial Strategy. The DISCnet CDT also engages in this arena and facilitates two-way knowledge exchange between academia and industry. Similarly, the DCE-CDT aims to create an industry-accessible research environment, and address EDI challenges in doctoral research.

4.4 Contribution to economy and society

4.4.1 Public engagement in research

The School has an illustrious history of public engagement, with well-established pathways for cultural engagement – and effective mechanisms supporting these. The School:

1. Has a **Public Outreach Director** (Berman, member of the STFC public engagement strategy panel) – and an Outreach Champion in each research group to advise on engagement and outreach opportunities at the research design stage, and incorporate impact activities into grants. QMUL's Centre for Public Engagement provides additional support in the design,

Unit-level environment template (REF5b)

implementation and evaluation of our outreach, and was the first recipient of the National Co-ordinating Centre for Public Engagement's Gold Engage Watermark;

2. Organises an **extensive outreach programme**, including public lectures, social media engagement, school visits, contributions to national events such as the Royal Society Summer Exhibition, and public research open days;
3. Has **partnerships** with the Ogden Trust, SEPnet and the Millennium Maths project, leading to the delivery of **joint projects** such as 'Researching the unknown';
4. Developed the **internationally recognised 'Physics Research in School Environments' (PRiSE) programme**, which was shortlisted for a Times Higher Education award in 2019 (see separate case study);
5. Appointed Becky Parker MBE, founder of the Institute for Research in Schools (IRIS) and winner of the Royal Society's Kavli Education Medal in 2016, as a **visiting professor to provide leadership and experience with schools outreach**;
6. Appointed **Ben Still as a visiting fellow**, to continue his Lego-based particle physics work for schools and science festivals. Still's book on this approach has had a notable impact and accrued sales of nearly £100k;
7. Has a named '**cultural engagement leader**' (Berman) who, by partnering with galleries, has created internationally recognised work at the interface of science and the arts. This builds upon our REF2014 impact case on arts engagement, where the School was acknowledged as a national leader;
8. Has a **strong representation in the media**, with School members appearing on BBC News, 'In our Time' and BBC Radio 4's 'Today' programme. The reach of these appearances is enhanced by BBC archives, with over 8 million people downloading the 'In our Time' podcasts; and
9. Has **75% of its academics involved with outreach activities** over the REF period.

Additionally, the number of public engagement events has grown, as shown in *Figure 5*, with several involving audiences of over 1000 (note that the drop in 2020 is Covid-related, though school-based events continued remotely where possible).

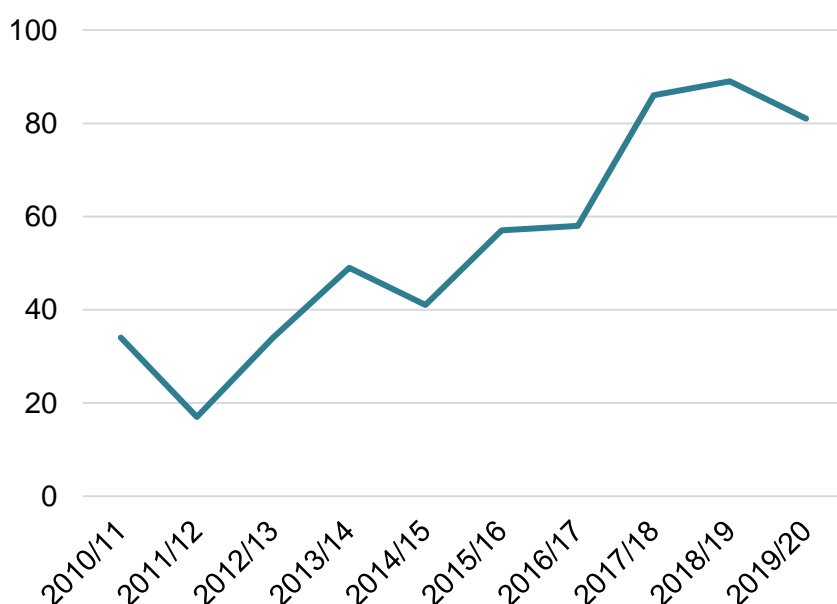


Figure 5. Number of public engagement events.

4.4.2 External collaborations – industry and policy work

The School maintains several international working relationships and has built upon its broad contacts to carry out diverse research in collaboration with global organisations and governments:

Associated academic	Details
Trachenko, Dove and Drew	Signed a research and data-sharing agreement with the International Atomic Energy Agency.
Drew	Collaborates with the Indonesian Atomic Energy Agency on structural materials characterisation; advises the Indonesian Ministry of Energy and Mineral Resources and Ministry of Research and Technology, and has co-founded the National Battery Research Institute .
Gillin	Launched a spin-out company, Chromosol Ltd. in 2017 (with investment from IP Group Ltd. and Innovate-UK), which secured a total of £875K in venture capital investment prior to July 2020. Coupled with grant funding, this enabled them to expand to 6 employees.
Dunstan	Collaborates with: Absolute Action Ltd on bespoke lighting for crystals at the Smithsonian (USA) and Natural History (UK) Museums, station canopies on the Washington Metro and artworks in private/stately residences; Renishaw plc on optics and software in their Raman spectroscopy systems.
Dove	Integrated new crystal structure analysis methods into CrystalMaker software (the flagship product of the eponymous UK SME, and used internationally by academics, governments and industry). Received an Innovate-UK grant.
Berman	Participated in a project for a major global bank (embargoed by NDA) on applying machine learning to operational risk in banking.
Bevan and Kreouzis	Signed a technology license agreement with Symetrica and began a new collaboration with Micron Semiconductor Ltd, both as a result of AWE contracts totalling £228k (for developing organic semiconductor thermal neutron detectors).