Institution: Queen Mary University of London (QMUL)

Unit of Assessment: Physics (UoA9)

a. Overview

Research within the School of Physics and Astronomy (SPA) at QMUL is undertaken within four leading Research Centres: the Astronomy Unit (AU); the Centre for Research in String Theory (CRST); the Particle Physics Research Centre (PPRC); the Centre for Condensed Matter and Materials Physics (CCMMP). The CCMMP is an integral part of the School, its research strategy and environment, but also plays a leading role within the cross-faculty Materials Research Institute. It is being submitted in UoA13b as part of a multidisciplinary materials submission. The School's Research Committee, chaired by the Director of Research, develops research strategy and monitors and supports its implementation. The School sits within the Faculty of Science and Engineering (S&E) led by a Vice-Principal (VP). The Dean of Research in S&E reports to the VP, and hosts regular faculty research strategy meetings with the Directors of Research, ensuring that the School's strategic priorities are incorporated into the College's strategic vision and vice versa.

b. Research strategy

The School's primary strategic aim is to maintain and enhance the excellence of its research, and the stimulating and enabling environment from which it grows. The research strategy builds on existing strengths, and through identification of areas requiring development since RAE2008. It is informed by objectives in the *QMUL Strategic Plan 2010-2015* and *Research Strategy 2012-2015*. The Research Committee, chaired by the Director of Research, defines the overarching School strategy with input from the Research Centre Heads, and monitors the attainment of strategic objectives across the School. The Director of Research reports to the SPA's Senior Management Team, which includes the Director of Teaching and Learning, the School Manager, and is chaired by the Head of School, ensuring that all decision-making is informed by research priorities. A Workload Allocation Model is used to assign teaching and administration duties within the School. Academic staff are allocated 50% of their contracted hours for research on average, and staff with grant support receive additional research-time commensurate with the funding level.

Strategic objectives 2008-2013: A key element of School strategy is to focus research in four Research Centres working in key areas of physics under excellent leadership. Area-specific priorities are defined within each Centre. The overarching strategic objectives pursued across the School since RAE2008 are: (i) To produce research of the highest standard, and to enhance the strength and breadth of research activity; (ii) To set international research agendas and contribute widely to the discipline through involvement in experiments/missions and engagement with national and international bodies, peer review and conferences; (iii) To provide an intellectually stimulating and nurturing environment conducive to the production of high-quality research and the recruitment and retention of high-calibre staff; (iv) To increase and diversify total grant income, PDRAs and research fellowships as a means of increasing research quality and volume; (v) To produce high-impact research that leads to significant public engagement or commercial benefit; (vi) To increase PhD student numbers and completion rates through improved training and monitoring; (vii) To improve the School's research infrastructure through targeted investment; (viii) To maintain strong interactions between the Research Centres to enhance interdisciplinary research and collegiality.

Strategic achievements and developments 2008-2013

(i) Since 2008 SPA staff have published 3195 journal papers, an increase of 55% over RAE2008.
(ii) In 2008 The School of Physics had two formally constituted research centres: the Particle Physics Research Centre (PPRC) and the Centre for Research in String Theory (CRST). In line with the School's strategy, a new Centre for Condensed Matter and Materials Physics (CCMMP) was formed in 2011, incorporating existing and new research under the direction of Prof. Martin Dove, appointed from Cambridge along with Misquitta, Philips and Trachenko. £800K has been invested in the CCMMP since it was established, on staff, PhD students and equipment.
(iii) The Astronomy Unit, then located in the School of Mathematics, was submitted to RAE2008 with Physics in UoA19. In 2011, the AU merged with Physics to form the new School of Physics and Astronomy (SPA), enabling the School to coordinate its strategy across all Research Centres.
(iv) Since 2008, 15 academic staff appointments have been made, strengthening and broadening each Research Centre. Including the AU merger, the School has doubled from 23 academics in 2008 to 50 in 2013, including three fellowship holders with proleptic lectureship appointments.

(v) Total grant expenditure *across the whole School* during 2008/13 was £18.5M, versus £14.1M (excluding the one-off VISTA grant) in 2001/7. Excluding the CCMMP, the figures for UoA9 are £15.9M for 2008/13 versus £13M for 2001/7. Total grant awards across the School since 2008 stand at £26.5M (£22.9M for UoA9). The mean number of externally funded PDRAs/research staff employed per year within UoA9 was 20.2, averaged over the REF period.
(vi) A £12M refurbishment is transforming the School building and research environment. Prior to this £6.5M was invested in improving the Physics building and infrastructure since 2008. These investments demonstrate QMUL's commitment to supporting the School's long-term sustainability.
(viii) The number of PhD students in the School stands at 96, compared with 28 at RAE2008. 53 PhD students have graduated from across the School since 2008 (39.8 FTEs from UoA9).
(ix) The School is a founder member of the South East Physics Network (SEPnet), set up in 2008 to enhance Physics student numbers in the South East and thereby strengthening the discipline in teaching and research. Of particular value to the SPA has been the sharing of advanced courses between institutions for PhD training, the support provided for our extensive outreach and schools engagement programme, the funding for staff and PhD positions, access to the Low Frequency Array (LOFAR), and opportunities for sharing ideas and best practice at regular SEPnet meetings. SEPnet2 will run between 2013/18 with a £13.1M investment being shared between its institutions.
(x) Interaction between the Research Centres is maintained through School colloquia, and the annual Physics Interdisciplinary Forum where members of each Research Centre present their research. These are followed by social events to promote discussions.

Future strategy: The strategy followed since 2008 has enabled a rapid expansion in research power and quality. As well as the growth in staff, PhD numbers and grant income noted above, the School has seen continuous growth in UG student numbers: the 1st year intake in 2013 was 132 compared with 38 in 2008. This has brought additional financial strength and opportunities for expansion and diversification. The School will continue to support research within the existing Centres, and hire staff of the highest calibre, to meet its long-term objectives. The expansion of the School has provided new opportunities for collaboration (Cosmology/ String Theory; Condensed Matter/Planetary Formation) that we are developing. We aim to diversify the School's research portfolio into new areas of applied physics to increase and diversify research funding, increase opportunities for knowledge exchange and industrial partnerships, and to address the impact agenda. We will focus on increasing the impact from our research across all Research Centres, and will appoint a Director of Innovation to coordinate activities that lead to commercialisation opportunities. We will implement measures to increase the level of grant funding and associated PDRA support across all Research Centres by improving our mentoring and internal peer review processes for applications. We aim to increase the number of fellowships hosted by the School through improved targeting of potential candidates and enhanced support in developing their applications. Achieving these aims will enable us to fulfil the central goals of our future strategy: increasing the quality, volume and impact of our research.

Research Centres: The Astronomy Unit (AU) is a leading astronomy research centre, comprising 18 academic staff (including a Royal Society URF and STFC Advanced fellow), a research-active teaching fellow, 2 research-active emeritus professors, 6 PDRAs and 17 PhD students. During the REF period we hired 7.3 PDRA FTEs per year on average and graduated 16 PhD students. The AU's specific research aims are to produce research of the highest quality in key areas of astrophysics. A core element of the strategy is to focus activity on broad themes: *Cosmology*, *Planetary Formation and Dynamics*, *Space & Solar Plasma Physics*, and *Survey Astronomy*. These are selected by considering local strengths and UK and international strategic planning, with emphasis on STFC priority areas and supported missions and facilities. A lively environment is maintained through weekly Astronomy and Relativity & Cosmology seminars, journal clubs, PhD seminars and social events that promote interactions with external speakers.

Since 2008 AU staff have published 397 journal papers versus 384 at RAE2008. In observations we have led developments in survey astronomy through the commissioning and exploitation of VISTA, leading to discovery of the 2nd - 4th highest red-shift quasars known and determination of star formation histories in the Magellanic Cloud (Sutherland, Emerson). We have played key roles in the Cassini mission explaining complex structures in Saturn's F-ring (Murray), and in the CoRoT (Roxburgh) and Rosetta missions (Williams). Our exoplanet discovery programmes have found habitable-zone planets and microlensing planets (Anglada-Escude, Tsapras). Our commitments to

future missions include Solar Orbiter and Solar Probe Plus (Burgess), JUICE (Murray), EUCLID (Malik), and the proposed ESA missions PLATO and EChO (Nelson, Cho). AU research has notable strengths in theoretical astrophysics. The *Cosmology* group specialises in the study of the early and late universe, calculating higher-order observables from inflationary scenarios (Lidsey/Malik/Tavakol), and pioneering studies of the cosmological consequences of non-linear and non-perturbative gravity (Clifton/Malik/Tavakol). The *Planetary Formation and Dynamics* group helped explain the giant impact origin of Mars' hemispherical dichotomy (Agnor), transformed our understanding of the evolution of planetesimals and planets in protoplanetary discs, and the dynamics of hot-Jupiter atmospheres, using state-of-the-art simulations and theoretical analyses (Nelson, Paardekooper, Cho). Highlights from the *Space & Solar Plasma* group include novel simulations of solar wind shocks and turbulence to explain spacecraft observations (Burgess) and PIC simulations of solar radio bursts for comparison with our LOFAR observations (Tsiklauri).

The future strategic aims of the AU are to increase the quality, impact and volume of its research, and to play an enhanced role in setting international research agendas. To achieve these we will build the strength of existing groups, and broaden activity by enhancing observational activities to complement our leading theoretical work. We aim to identify and hire the next generation of researchers with proven leadership capability, and whose interests support and extend existing activities, as exemplified by the recent arrivals of Clifton, Paardekooper and Anglada-Escude. Retirements post-2014 will provide opportunities for strategic hiring.

The Centre for Research in String Theory (CRST) builds on a recognised history of achievements in string theory, M-theory, dualities and supersymmetry. Since 2004 the Centre has also become a leader in modern methods for scattering amplitudes. The CRST comprises 10 academic staff, it has hosted on average 2.3 PDRAs per year since 2008, and has graduated 16 PhD students. The CRST's specific strategic goals are to produce research at the forefront of string theory, (non-) perturbative field theory and amplitudes, which remain primary foci in theoretical high-energy physics world-wide. Success in achieving these goals is demonstrated through the 149 journal papers published by CRST staff since 2008, compared with 115 at RAE2008. Members of the CRST have a high profile as demonstrated by over 50 plenary talks, numerous international visits and by being lead organisers of international conferences and workshops since 2008, including co-initiating the *Amplitudes* conference series.

Key contributions in the area of amplitudes such as the Wilson loop/amplitude duality and dual conformal symmetry (Brandhuber/Spence/Travaglini) have cemented the reputation of the CRST as a leading group. Highlights in string theory include innovative work on generalised geometry and string dualities (Berman), the study of 1/8 BPS states and giant gravitons in AdS/CFT and novel connections between topological theories and Feynman graph counting (Ramgoolam), and constructions of novel classes of superconformal theories and new models of supersymmetry breaking (Wecht). In Papageorgakis (Royal Society URF), CRST has appointed a leader on branes in M- and string-theory. Grants awarded to CRST since 2008 total £2.9M. Our success in developing strong national and international links is demonstrated through involvement in two funded EU Networks, strong association with leading research groups, e.g. the Universities of Cambridge, Witwatersrand (Johannesburg) and Tor Vergata (Rome), and through involvement with the NExT institute (**N**ew Connections between **Ex**periment and **T**heory).

The high international reputation and visibility of CRST secures a continuing ability to attract outstanding staff, as evidenced by the recent hiring of Wecht, Papageorgakis and Young. The excellence of our PhD student provision is reflected by the fact that 8 of the 16 PhD students found postdoctoral positions overseas while the rest forged successful careers in industry. PDRA recruitment is highly competitive and successful: five of the nine PDRAs since 2008 secured permanent faculty positions. The influx of high-calibre researchers helps the Centre to maintain a stimulating environment, further supported by weekly seminars, which include social events to enable discussions with speakers, a programme of joint seminars - the *London Triangle* (organised jointly with theory groups at Imperial, King's College and City University), and a weekly journal club. Furthermore, the group regularly hosts long-term visitors who enhance the vitality of the group by contributing to our graduate lecture series and through discussions and collaborations.

In the future the CRST plans to increase the breadth, impact and quality of its research, enhance its leadership in areas of high international activity and engage with promising areas of physics by exploring synergies with other groups within the SPA. Future appointments will be aimed at

strengthening and broadening existing areas of success and will target high-calibre, early career researchers such as our most recent hires. The CRST aims to increase grant income and PDRA support by focusing on diversification of funds and improving our internal grant application mentoring process. An important goal is to expand our network of international collaborations, by intensifying links with existing partners (e.g. CRST will soon host joint PDRAs from Witwatersrand), and fostering new links via our participation in international networks, conferences and workshops.

The Particle Physics Research Centre (PPRC) operates at the forefront of experimental particle physics. It comprises 9 academic staff, 7 PDRAs, 1 senior research fellow, 1 applied physicist, 23 PhD students, 2 senior technical engineers, and 2 physicist-programmers. Two full-time system managers provide maintenance of GridPP infrastructure. Since 2008 we have hosted an average of 10.5 PDRAs/research staff per year, and graduated 8 PhD students. The long-term strategy has been to address the most fundamental particle physics questions with a portfolio of experiments at high energy and high intensity frontiers, focusing on experiments that STFC places at maximum priority, at different stages of planning, construction and analysis. During the REF period our priorities have been the LHC and T2K experiments, and building links with phenomenologists and theorists through SEPnet, the NExT institute and the IPPP in Durham. Within NExT we have initiated a joint PhD programme with Southampton. A weekly seminar programme with talks from external speakers, followed by lively discussion, helps maintain a stimulating environment.

In the last decade PPRC was heavily involved in construction of the ATLAS detector, and more recently T2K, along with the associated software and computing. QMUL is one of the largest ATLAS Group Analysis Tier-2 sites, and significant resources and staff time have been invested in maintaining and testing the GridPP systems to ensure that they are able to contribute centrally to the analysis of high-profile events such as detection of the Higgs boson. Both ATLAS and T2K were completed in 2010 and have been taking data since then. The success of the PPRC's strategy is demonstrated by the 2406 journal papers published since 2008, compared with 1403 from RAE2008. Highlights include the discovery of the Higgs boson by the LHC in which QMUL played a leading role through its direct contribution to the main analysis of CMS data (Hays), and through the development and management of the GridPP infrastructure to ensure its effective contribution to the analysis (Lloyd). CMS and ATLAS both receive mention in the 2013 Nobel Prize press release. PPRC researchers are also involved in understanding additional Standard Model physics and searches beyond the Standard Model in ATLAS (Bona, Cerrito, Lloyd, Rizvi). Another highlight is the first observation of electron neutrino appearance in a muon neutrino beam at T2K (Di Lodovico, Wilson), and the measurement of CP violation in BaBar (Bevan, Di Lodovico). The BaBar experiment received mention in the 2008 Nobel Prize press release. Since 2008 the PPRC has been awarded a total of £12.7M in grants. We expect that high levels of GridPP support will continue for several years due to our role as one of the largest ATLAS Group Analysis Tier-2 sites.

Looking to the future, the PPRC is heavily involved with forthcoming or planned experiments. Construction of SNO+ has been completed and data taking will start next year. Upgrades to the ATLAS Inner Detector and Trigger are in the R&D phase, and generic R&D on metal oxide semi-conductor (CMOS) devices is underway. Planning for a new long baseline neutrino (LBN) project in Japan, Hyper-Kamiokande, has started. Feasibility studies for an EU LBN (LBNO), are under way. We are also joining the PINGU experiment in Antarctica, and have recently joined the International Linear Collider and the muon g-2 experiment at Fermilab. Future strategy for the PPRC centres on continued participation in the highest priority international experiments. The medium term future (~5 yrs) will be ATLAS, T2K and SNO+ analysis. The longer term (~10 yrs) will be continued ATLAS physics analysis, upgrades to the ATLAS and T2K (Hyper-Kamiokande) detectors, PINGU, particle-astrophysics initiatives, the anomalous magnetic moment of the muon, and linear colliders.

The Centre for Condensed Matter and Materials Physics (CCMMP) brings together longstanding experimental strengths (semiconductors, optical materials) with new research on structure-property relations, disordered materials and radiation damage. A key element of the SPA's research strategy has been to expand the CCMMP. It now comprises 12 academics, 2 PDRAs and 44 PhD students, and is being submitted in UoA13b as part of a multidisciplinary materials submission.

c. People, including:

i. Staffing strategy and staff development

Since RAE2008 the School has appointed 15 new staff members and has merged with the AU, increasing staff numbers from 23 to 50. Retention has been excellent - the School has not lost an

academic to another institution since 2008, despite numerous recruitment attempts. The School's staffing strategy is to recruit the highest calibre researchers to strengthen the existing Research Centres, to actively seek out opportunities to expand into new and thriving areas, and to provide strong support for the careers of existing staff. Sustained investment in outstanding new staff has occurred since 2008. Clifton (Oxford), Paardekooper (Cambridge), Anglada-Escude (Goettingen) have joined the AU. Wecht (Harvard), Papageorgakis (Rutgers), Young (Stockholm) have joined the CRST. Wilson (Oxford), Hays (Imperial), Bona (CERN), Katori (MIT) have joined the PPRC. Recruitment of Dove's group from Cambridge (Misquitta, Phillips, Trachenko) and Drew (Fribourg) has established the CCMMP. All apart from Dove have been early career researchers, in line with our goal of maintaining a dynamic and forward-looking research culture. Three new staff hold fellowships: Clifton (STFC AF); Paardekooper, Papageorgakis (Royal Society URFs). Six out of the 15 new academics are international appointments, as were 36% of our PDRA appointments. Since 2008 there have been 5 retirements and one resignation to pursue a non-academic career.

Support for new/early career staff and PDRAs: New academics are mentored by a senior member of their Research Centre, and attend a PGCAP course that provides comprehensive training during a 3-year probation scheme that sets appropriate targets. They have reduced teaching duties: tutorials-only in the 1st year and a 50% teaching load in their 2nd year, and receive priority allocation of PhD studentships that normally start in the 2nd year of employment. They are provided with start-up funds for travel and equipment. PDRAs are mentored by and receive career guidance from the academics that are their grant holders or sponsors. All PDRAs are provided with teaching opportunities to enhance their CVs. Queen Mary's EPSRC Knowledge Transfer Account has been used to support a Training and Internship Programme for PhD students, including Kotub Uddin from the SPA who secured a placement (and then a permanent job) at Jaguar Land Rover Advanced Engineering. This programme was recognized nationally by being shortlisted for the 2011 THES Award (Support for Early Career Researchers).

Support for existing staff: All staff members benefit from the School's flexible approach to working, with staff supported if they need altered hours for family or other commitments. Annual appraisals encourage staff and PDRAs to set career goals and identify the necessary support and training for advancement. QMUL's *Centre for Academic and Professional Development* offers skills training tailored to meet the needs of research and academic staff at all levels. Topics include: research project management, creative thinking, research leadership and management. The School has a sabbatical policy of one year in seven to support research and career development. Since 2008 the equivalent of 17 one-year sabbaticals have been granted. There have been 13 promotions to Senior Lecturer or Reader and 5 promotions to Professor, and 16 out of 50 SPA staff hold chairs. QMUL is committed to the seven principles enunciated in the Concordat to Support the Career Development of Researchers, and received the 2012 European Commission's *HR Excellence in Research* award in recognition of continued commitment to the development of our researchers.

Equality and Diversity: In 2010 QMUL successfully renewed its Bronze Athena SWAN Award for excellence in recruiting and advancing the careers of women in science, engineering and technology. The School was awarded IoP JUNO Supporter status in 2010, followed by JUNO Practitioner status in 2013, and will be applying for JUNO Champion in 2015. The School has initiated an Academic Returners support scheme for staff that experience planned long-term absence (e.g. maternity leave). The scheme provides a PDRA for up to 15 months to continue the academic's research during their absence and to assist them in their return to work. All members of the School are encouraged to participate in the faculty WISE (Women in Science and Engineering) initiative, which is a networking group aimed at enhancing female participation across all aspects of STEM. Queen Mary is a member of the Stonewall Diversity Champions programme, which assists employers in improving the workplace environment for lesbian, gay and bisexual staff.

The success of the School's staffing policy in creating a positive work environment is demonstrated by our excellent staff retention record and by an independent Staff Satisfaction Survey (2011). Satisfaction levels were in the top 3 out of 32 departments at QMUL. Staff numbers reporting satisfaction with work as 'generally high' was 90%. 94% reported feeling 'part of the department'. Details about the School's *visitors* are given in section e along with details about collaborations.

ii. Research students

The School's strategy has been to increase PhD student numbers and the quality of its PhD training. The PhD cohort has risen from 28 in 2007 to 96 in October 2013. This increase has been

accompanied by significant improvements in their care and management. 53 PhD students have graduated from across the School since 2008 (39.8 FTEs from UoA9). The submission rate within four years for the School during the REF period was 88%. During 2011-2013 it has been 100%. Recent large increases in numbers have been achieved by diversifying our funding sources to include: EPSRC, STFC, ERC, SEPnet, QMUL funds, and the China Scholarship Council.

Recruitment, training and support: The School's Graduate Degrees Committee (GDC), chaired by the Director of Graduate Studies, oversees postgraduate (PG) recruitment and training. Each Centre has a PG Tutor who sits on the GDC. Recruitment involves advertising, short-listing and face-to-face interviews undertaken by three academic staff, two of who will not be involved in supervision of the candidate. This process is monitored by the PG Tutors who report to the GDC.

New PhD students are assigned a primary and secondary supervisor, and attend an induction programme hosted by QMUL's *Centre for Academic and Professional Development* (CAPD). The School also runs induction and social events that provide information on procedures and expectations, and smooth the transition into the new environment. The primary supervisor guides the research and assists in designing an appropriate programme of academic and transferable skills training. The programme differs between Research Centres, but involves advanced physics lectures and language support for non-native English speakers. A wide range of advanced lectures is available within SEPnet and through access to courses at major London universities. QMUL requires all PhD students to undertake 210 hours of developmental activities during a PhD. They include research-related activities (lecture/seminar attendance, presenting talks, computer-skills training), and transferable skills training provided by the CAPD. An overarching *Doctoral College* was established at QMUL in 2012, the role of which is to provide oversight and activities across all faculties. The *Doctoral College* organises an annual *Junk the Jargon* competition, where PhD students present their work to a public audience in 3-minutes and are judged by an external panel and the audience. 1st prize in 2013 was awarded to the SPA's Evelina Arushanova. PhD students are encouraged to develop their teaching skills through demonstrator roles working with UG students, for which they receive rigorous in-house training. Each Research Centre organises seminars and journal clubs and student attendance is compulsory. The School runs an annual student poster competition, and posters are judged and prizes are award by a member of the QMUL senior executive. From 2013 onward PhD students will benefit from GradNet, a PG network that is being set up as part of SEPnet2. This will provide bespoke activities across SEPnet and will replace the more general training programme now in place. PhD supervisors, PG Tutors, the student support officer, and the Director of Graduate Studies provide pastoral support within the School. Professional support is available through the College's Advice and Counselling service.

Monitoring: Progress toward completion of the PhD is monitored through twice-yearly reports to the GDC by all PhD supervisors. Progression from the 1st to 2nd year is determined after 9 months. Students submit a written report and undergo a viva with two academic staff not involved in the project supervision. Students also submit reports and have interviews at the end of the 2nd and 3rd years. The latter report must include a thesis plan to ensure that submission will be within 4 years.

d. Income, infrastructure and facilities

Income: Total grant expenditure *across the whole School* during 2008/13 was £18.5M, versus £14.1M (excluding the one-off VISTA grant) in 2001/7. Excluding the CCMMP, the figures for UoA9 are £15.9M for 2008/13 versus £13M for 2001/7. All Research Centres have achieved growth since RAE2008: AU (£5.3M vs £4.7M); CRST (£2.3M vs £1.8M); PPRC (£8.3M vs £6.4M); CCMMP (£2.7M vs £1.1M). Total grant *awards* across the School since 2008 stand at £26.5M (£22.9M for UoA9): AU (£7.2M); CRST (£2.9M); PPRC (£12.7M); CCMMP (£3.6M). Significant diversification of income sources has been achieved: STFC (18.7M); EPSRC (2M); ERC + EU FP7 + Marie Curie (£4M); Royal Society (£1.1M); Leverhulme (£403K); BBSRC (£90K). The SPA's operating surplus was £2.1M in 2012/13, compared with £1.2M in 2007/8, due to rising grant income and student numbers, demonstrating dramatic improvement in financial sustainability.

Future plans: The School aims to increase research income by improving internal mentoring and peer review to maximise grant application success rates, and by diversification of funding sources. These sources include the EU's Horizon 2020 programme, where we aim to build on our past successes in securing ERC grants. We will build partnerships in the EU to increase participation in funded research networks. We will also improve our targeting and support for researchers applying for fellowships funded by Leverhulme, the Royal Society, STFC, and the Marie Curie scheme.

Local infrastructure and facilities: In 2012 QMUL approved a £12M renovation of the entire physics building. By September 2014 each Research Centre will be housed within an individual area of the building with bespoke office, visitor, seminar/meeting space, with the CCMMP/PPRC laboratories being completely refurbished. Prior to this renovation QMUL invested £6.5M in infrastructure for Physics and Astronomy between 2008/11. This funded a new teaching laboratory, HPC facilities, and refurbishment of lifts, lobbies, offices, lecture rooms and research laboratories.

The CCMMP have 100m^2 of class 10,000 clean room space used for organic electronics, spin-tronics and photonics research. It includes 3 high vacuum organic deposition systems for device fabrication (e.g. OLEDS, solar cells), and facilities for photolithography, optical and electrical characterisation as a function of temperature and magnetic field (down to 4K and up to 7T). Organic materials research uses time resolved optical spectroscopy facilities (215 to 2650 nm excitation with 5ns pulse width, detection from UV to near-IR). The PPRC have a 35m^2 class 10,000 clean room housing an Alessi semi-automatic probe station. This is one of two global centres for silicon sensor qualification for the ATLAS barrel silicon strip detector upgrade due for installation in the LHC post 2022. There is 73m^2 of laboratory space with environmental chambers for ageing and QA qualification tests, test equipment for electronic and mechanical QA testing, facilities for carbon composite manufacture and a rapid prototyper to facilitate design cycles for components and for the manufacture of small items. A metrology laboratory houses a CNC touch probe based CMM. In 2011 the School invested £240K in the refurbishment of its 148m^2 technical workshop that supports the research of PPRC and CCMMP. It now houses a state-of-the-art Hurco CNC milling machine and a HASS CNC lathe, vital for the ATLAS upgrade work and CCMMP experimental activity. In 2013 £170K was invested in an X-ray Diffraction Facility and associated upgrades for measuring pair-distribution functions for the CCMMP, adding to a £250K EPSRC award for upgrading the small equipment base. Future plans include provision of a test laboratory for CMOS-based sensors for future applications in particle physics detectors, and investment of £100K in an optical CMM to increase metrology capability. 4 FTE experimental officers/technical engineers and 3 FTE technical staff support these laboratories and facilities.

The PPRC manages one of the largest ATLAS Group Analysis Tier-2 GridPP facilities (3rd largest in terms of data volume processed), consisting of 3500 cores, 1.8 PetaBytes of disc storage and a 10 Gbit/s link to JANET. The AU also runs a HPC cluster consisting of 1856 cores and 30TB of disc space. Between 2008 and 2011 there were SRIF and CIF investments totalling £1M in these facilities (included in the above £6.5M figure), augmenting an investment of £0.7M by STFC in the GridPP system. Recent QMUL investment in HPC facilities has arisen through the EPSRC award in 2012 of a £2M Midplus Consortium grant to QMUL, Warwick, Birmingham, and Nottingham. QMUL involvement was led by the School (Dove), with the £350K EPSRC funds awarded to QMUL being matched by £250K from the College, establishing a Midplus cluster with 2328 cores and 220TB of disc space. A further College investment of £275K in HPC is currently underway.

National and international facilities: Staff in the PPRC work at CERN on the ATLAS and CMS Experiments (Bevan, Bona, Cerrito, Hays, Lloyd, Rizvi), JPARC on T2K (Di Lodovico, Wilson), and SNOLAB on SNO+ (Di Lodovico, Wilson), and use test beams at CERN and DESY. AU staff access international facilities through telescope time allocations and through Cassini and VISTA. Between 2008-2012 there were 835 sets of Cassini ISS observations for which Murray was responsible – these comprised 31% of all ISS observations. Emerson and Sutherland are involved as Co-Is in all 6 of the VISTA Public Surveys (13,000 hours on VISTA) and 2 of the 3 with the VLT Survey Telescope (875 hours). Since 2008 Tsapras was awarded 2100 hours (£840K) on the Faulkes (N&S) and Liverpool telescopes through competitive time allocation. Anglada-Escude was awarded 4.5 nights on Keck ($53700/night), 4.5 nights on VLT (€40000/ night), 8 nights on the 6.5m Magellan telescope ($23149/night), 21 nights on the ESO 3.6m La Silla telescope (€1500/night), 33 nights on the TNG (€1500/night), 27 nights on the NASA IRTF 3.5m telescope ($1500/night), 52 nights on the Dupont 2.5m telescope (€1500/night), 16 nights on the Liverpool 2m telescope (£2400/per night). Nelson used 10^6 core-hrs (£60K) on DiRAC HPC facility 2012/13.

e. Collaboration or contribution to the discipline or research base

A strategic objective of the School is to contribute widely to the Physics discipline through research collaboration, conference organisation/participation, and by adopting leadership roles in national and international bodies. The School actively supports these activities by funding overseas visits by SPA staff and incoming visits by external collaborators, and provides financial and staff support

for locally organised workshops/conferences. These activities are recognised as key performance indicators in appraisals and promotion criteria.

Research collaborations and visitors: The SPA has hosted more than 100 visitors since 2008, many of who are active collaborators with members of the School. The Research Centres maintain strong international links through involvement with experiments, facilities and research networks. Visiting collaborators to the AU include: Bale (Berkeley), Bojowald (Penn State), Bond (CITA), Charnoz (Paris), Brandenberg (NORDITA), Dermott (Florida), Ellis & Dunsby (Cape Town), Fromang (Saclay), Hamilton (Maryland), Jeffries (Hawaii), Nicholson (Cornell), Passot (Nice), Turner (Caltech), Yokoyama (Tokyo). Collaborations through involvement with facilities/missions include: Solar Probe Plus (NASA) Fields experiment + Solar Orbiter (ESA) Magnetometer, Particles, Fields experiment (Science team member, Burgess); Imaging Science Subsystem team on Cassini plus Co-I on ESA's SMART-1 D-CIXS instrument plus JANUS Camera Science Associate on ESA's JUICE mission (Murray); ESA CoRoT Scientist plus Kepler Asteroseismic Science Consortium member (Roxburgh); EPSRC CPP consortium and STFC UK-MHD consortium member (Tsiklauri); 6 VISTA Public Surveys plus 2 VST Public Surveys (Sutherland, Emerson), Herschel ATLAS and GAMA (Sutherland); EUCLID Theory Working Group (Malik); Co-I on Rosetta CONSERT Instrument (Williams). The CRST publishes more than 50% of its papers with international colleagues and has extensive links through its funded EU networks *The String Theory Universe* and *Gauge Theory as an Integrable System.* A new initiative with Witwatersrand will bring joint PDRAs to QMUL from 2014. Visiting collaborators to the CRST include: Anastasiou & Beisert (ETH Zurich), Bianchi (Rome), de Mello-Koch (Witwatersrand), Dixon (Stanford), Green (Cambridge), Korchemsky (Saclay), Penrose (Oxford). The PPRC is intertwined with a global research programme and involves extensive international collaborations through its experiments at ATLAS, CMS, T2K, SNO+ and GridPP. Collaborating visitors to PPRC include: Prell (Iowa), Mannel (Siegen), Orebi (Berkeley), Starkman (Case Western), Dixon (Stanford). CCMMP has strong links with Sichuan University that involves a visitor programme that extends to other Chinese universities (Nanjing, Fudan), in addition to hosting visitors from around the globe.

Conference organisation and invited lectures: Since 2008 SPA staff have participated in the organisation of 56 international conferences/workshops, some hosted at QMUL. These include: two 6-month research programmes and associated conferences at the Isaac Newton Institute (Berman**,** *Mathematics of Strings and Branes,* 2012; Nelson, *Dynamics of Discs and Planets,* 2009); lead convenor for EGU sessions on Extrasolar Planets and Planet Formation (Cho, 2008-2013); lead coordinator of Kavli Institute of Theoretical Physics programme *Wave-flow interaction in geophysics, climate, astrophysics* (Cho 2014); organising committee for the conference *Amplitudes 2010* hosted at QMUL (Brandhuber, Spence, Travaglini); LMS Durham Symposium *Polylogarithms as a Bridge between number theory and particle physics* (Travaglini 2013); *2nd Johannesburg workshop on string* theory (Ramgoolam 2010); Lead organiser of *Future Long Baseline Neutrino Experiments* hosted at QMUL (Di Lodovico 2012). SPA staff have given more than 100 invited talks at international conferences and workshops. Highlights include: ESLAB conference *Formation and Evolution of Moons* (Agnor, 2012); *13th Marcel Grossman meeting* (Clifton 2012); *Amplitudes 2010/12* (Brandhuber, Travaglini); *Strings2013* (Berman); *Harmony of Scattering Amplitudes* 2011 (Travaglini); *Tau-Charm at High Luminosity 2013 (Bevan).*

Leadership in the academic community: The School has had extensive involvement in senior-level RCUK roles. Dove is chair of the STFC Futures Advisory Panel and STFC Science Board member. Lloyd, Murray, Nelson and Spence have chaired STFC grant panels. Other STFC review panel membership includes Cerrito, Di Lodovico, Drew, Emerson, Lidsey, Ramgoolam. Sutherland and Nelson are members of the STFC Astronomy and Computing Advisory Panels. Involvement with EPSRC panels includes Berman, Gillin, Trachenko and Travaglini. Staff have been active on governing and oversight bodies for facilities such as ISIS, GridPP, Herschel (Dove, Emerson, Lloyd). Emerson and Sutherland were P.I. and Project Scientist during commissioning of the VISTA telescope. Staff international roles include EU FP7 project "SHOCK" coordinator (Burgess), NASA review panel members (Agnor, Burgess) and panel member for the NSF LSST final design review (Emerson). Fellowships held since 2008 include: Leverhulme (Cerrito, Drew, Murray, Spence), STFC & EPSRC AFs (Berman, Clifton, Ramgoolam, Travaglini, Trachenko), Royal Society URFs (Paardekooper, Papageorgakis). Prizes awarded: Royal Astronomical Society (RAS) Fowler Medal (Tsiklauri 2009), RAS Group Award 2012 (UKIDSS consortium including Emerson).