Institution: University of Glasgow
Unit of Assessment: B9: Physics
a. Overview

Since RAE2008 the School has enhanced both sustainability and vitality. We have doubled our average research income per annum between the two review periods and increased our student numbers significantly (35% for PhD students; 45% for undergraduates, both since 2008 [HESA]) thus strengthening our funding base for a stable number of staff. Enhanced research output quality is seen in the increased number of Physical Review Letters published: 44 per annum on average in 2008-13 compared to 25 in 2002-7. External recognition of our staff has also grown. We now have in the School: 2 Fellows of the Royal Society; 13 Fellows of the Royal Society of Edinburgh; 3 Royal Society Wolfson Research Merit award holders and 3 Royal Society University Research Fellows. We have achieved this within a working environment recognised for its quality with Institute of Physics Juno Champion status and an Athena Swan Silver award.

The School has world class research programmes, ranging across pure and applied physics and astronomy, which are driven by a strong research group structure focused in six areas: astronomy and astrophysics (AA), the Institute for Gravitational Research (IGR), materials and condensed matter physics (MCMP), nuclear physics (NP), optics and imaging (OPT) and particle physics (PP). We are returning a total of 44.9 FTEs; this includes 98% of our research and teaching academic staff. Physics and Astronomy is one of seven Schools in the College of Science and Engineering (headed by **Chapman**), formed in 2010 in a major University of Glasgow restructuring designed to promote research excellence and enhance interdisciplinary activity. It is also a founding member of the Scottish Universities Physics Alliance (SUPA), launched in 2005 with backing from the Scottish Funding Council (SFC). SUPA is now in Phase II (2009-2017), has received total SFC and university investment of £48m and has grown to comprise 8 universities. **Hough** is the current SUPA CEO.

b. Research Strategy

The core of our strategy builds upon our key objective from RAE2008: to enhance our international leadership by developing young researchers of the highest quality. To this end we have made 9 lecturer, 1 reader and 3 professorial appointments since 2008, maintaining a good age profile: half of our staff are under 45. Our research profile is balanced with critical mass in each area. There is cross-linking between research groups and with other disciplines in the College, and further afield, that stimulates and enables new initiatives. Our research strategy addresses major challenges in fundamental and applied physics through its close alignment with STFC and EPSRC priorities and with key elements of the College corporate plan: to develop an environment in which both core and multidisciplinary research thrives, to increase PGR numbers and to diversify our income streams. Our strategic planning is driven by the School Management Team and Research and Strategy Committee comprising research group leaders. To meet group strategic initiatives we operate a 'PI incentivisation model' that returns to research groups funds proportional to FEC grant income won (£235k returned in 2012-13).

Achievement of strategic aims: overview

In 2008 we foresaw a broadening of our work in condensed matter following two senior retirements, along with the development of new strands in the recently formed OPT group. This strategy has been implemented, with support from SUPA Phase II, through new professorial appointments (**Harvey** and **Stamps**), lectureships (**D. Maclaren** and **Taylor**) and £2.4m of investment in new electron microscope facilities. Unforeseen in 2008, but also in line with this strategy, has been the recent appointment of **Barnett** and **Croke** in optics. **Barnett** and **Stamps** provide significant added weight in theoretical physics and **Harvey** in applied physics.

Our groups working in 'big science' areas (PP, IGR, NP and AA) have been well placed, through international leadership roles, to exploit the unprecedented quality and quantity of data coming from the LHC at CERN, LIGO and Jefferson Lab in the USA and the RHESSI satellite. We have made strong junior appointments to ensure future leadership. In these areas, during the SUPA II period, £2m of investment in facilities and infrastructure has gone into: the new Glasgow Laboratory for Advanced Detector Development (GLADD); beam line equipment for the SCAPA

wakefield accelerator under construction at Strathclyde; clean rooms for R&D for the LISA gravitational wave space mission; support for the LOFAR radio telescope.

Forward vision: overview

Our groups have strong future plans with enormous physics potential. In our 'big science' areas these include LHC upgrades (in energy 2015 and luminosity 2020), start of Advanced LIGO and launch of LISA Pathfinder (2015), launch of Solar Orbiter (2017), JLAB 12 GeV upgrade (first experiments 2015). We will maintain and, where possible, enhance our leadership profile within these large international projects. New initiatives will provide further opportunities; in the next few years these will focus particularly on the International Max Planck Partnership (IMPP) and the Innovation Centre in sensing and imaging systems (CENSIS). The IMPP is the first venture of its kind: 5 Scottish universities, led from Glasgow by **Hough**, linked with 5 Max Planck Institutions. Its programme includes research in IGR, OPT and MCMP and has been kick-started by £3.3m of University of Glasgow/SFC/STFC/EPSRC investment. Physics involvement across Scotland in the £10m SFC-funded, University of Glasgow-led CENSIS programme for future technology translation is coordinated by **Harvey.** These initiatives are building on the strong collaborative links forged under SUPA, and will contribute to sustaining joint SUPA research in the future, including the successful pan-Scotland graduate School. Our interdisciplinary activity will increase, particularly with Engineering, building on existing collaboration and encouraged by College/University initiatives – e.g. networks in Imaging, Modelling and Simulation, Sensor Systems and Space.

Recent achievements and future plans by research group: staff returned; RAs, RSs, support staff for 2012-13, grants active in FY 2012-13, total refereed journal articles 2008-13

AA: Diver, Fletcher, Hannah, Hendry (0.5), Kontar, Mackinnon, Woan (0.5); 8.7 RAs, 11.0 RSs, 1.2 support; £2.7m grants; 174 journal articles

AA has long-standing expertise in plasma physics related to solar activity – theory, simulations, diagnostics and experiment. We are co-Is of the NASA-led RHESSI mission where we have contributed strongly to data analysis software and physics outcomes. Key results since 2008 relate to the characterization of energetic particles in solar flares and improved understanding of processes of particle acceleration and transport in the solar atmosphere. A spin-off from work on energy-exchange mechanisms in the solar plasma, backed by experimental work, has seen the development of new technology to prolong the shelf life of packaged food using plasma production of ozone. This is currently being commercialised by Anacail. Future research will extend solar work into the ultraviolet and optical using IRIS (launched 2013) and ATST (first light 2019) data. We are also science co-Is on the ESA-led Solar Orbiter (launch 2017) which will simultaneously observe phenomena at the Sun and their consequences in the heliosphere from a vantage point near Mercury's orbit.

IGR: Hammond, Hendry (0.5), Heng, Hild, Hough, Martin, Rowan, Strain, Van Veggel, Ward, Woan (0.5); 18.2 RAs, 16.0 RSs, 7.5 support; £15.0m grants; 178 journal articles

The IGR group has been instrumental in establishing the possibility of gravitational wave (GW) detection from long-baseline interferometers. We have designed and delivered the key low noise mirror suspensions in use in the GEO detector in Germany and being commissioned in Advanced LIGO in the USA (an £8m deliverable). We have also delivered the optical bench for the LISA Pathfinder mission (launch 2015) to demonstrate the feasibility of GW detection from space. Since 2008 we have expanded our data analysis programme and lead the continuous waves search group for the 800-strong LIGO Scientific Collaboration. Highlights include significant limits on the GW luminosity of known spinning neutron stars. This has positioned us to lead targeted searches using the first data from Advanced LIGO, where GW detection is anticipated. In parallel we lead one of three design teams for future upgrades to Advanced LIGO; this work includes developing improved amorphous coatings for the mirrors with MCMP. Techniques to beat the quantum limit on sensitivity using a Sagnac interferometer are the subject of an ERC starter grant (£1.2m) to **Hild**.

MCMP: Chapman, D. Maclaren, I. Maclaren, McVitie, Stamps; 6.0 RAs, 16.0 RSs, 4.4 support; £5.2m grants; 183 journal articles

The MCMP group has established world-first electron microscopy techniques that have been adopted by the leading microscope manufacturers. Our capabilities include unprecedented

resolution of magnetic materials, of particular interest to global firms such as Seagate and Hitachi in the IT data storage industry. Likewise, industries reliant upon high performance steels and other alloys [automotive (Thyssen Krup), nuclear (Amec)] and advanced materials [humidity sensors (Honeywell), renewable energy devices (Merck)] are benefitting from our enhanced rapid compositional analysis. Strategic hires support our expansion into multifunctional complex oxide materials (**D. Maclaren**) and multiphysics modelling and development of microwave and THz spin electronic materials (**Stamps**). Further expansion of capabilities is planned with ultra-high resolution magnetic imaging,and the fabrication of novel functional materials based on epitaxial oxide films and heterostructures. Additional advanced imaging will be developed through Glasgow's membership of the UK national facility, SuperSTEM.

NP: Annand, Ireland, Livingston, Macgregor, Seitz, Sokhan; 10.5 RAs, 8.0 RSs, 3.7 support, £5.0m grants; 169 journal articles

Since 2008 the NP group has played a major role in collaborations at Jefferson Lab (JLAB) in the USA, DESY and Mainz in Germany and MAX-Lab in Lund, Sweden. Recent successes include confirmation of new excited nucleons, discovery of novel features in nucleon spin structure and studies of short-range correlations between nucleons in nuclei. These were made possible by Glasgow's linearly polarized photon beam and components of the BigBite detector at JLAB and the recoil detector for HERMES at DESY. Key future physics goals around exotic hadron spectroscopy and nucleon structure will be realised through the JLAB 12 GeV upgrade where we are spokespersons for 5 experiments and **Ireland** is Chair of the CLAS Collaboration. Applications for monitoring radioactive waste using muon tomography are being developed with the National Nuclear Laboratory (£1.8m, 2011-2014) and in medical and environmental areas through SCAPA.

OPT: Barnett, Courtial, Croke, Franke-Arnold, Harvey, Padgett, Taylor; 10.0 RAs, 17.5 RSs, 1.9 support, £5.9m grants; 229 journal articles

We have pioneered the emerging field of optical orbital angular momentum, a fast growing area of modern optics. Key scientific achievements include observation of quantum correlations for angular variables, slow light in rotating media, generation of optical knots and tests of quantum mechanics in high dimensions. A new activity in imaging concepts was added in 2012 led by **Harvey,** innovating world-firsts in aberration-free hybrid optical/digital imaging and biomedical sensing. A 2012 EPSRC programme grant (**Padgett, Barnett**: £2m) and ERC Advanced grant (**Padgett**: £1.5m), together with **Barnett's** move to the University of Glasgow in September 2013 following a sabbatical year here, will enhance future joint experiment-theory activity. The goal remains that of producing better imaging, communications and sensing systems by application of light's momentum states. Multidisciplinary research in imaging will be taken forward through CENSIS.

PP: Britton, Buckley, Buttar, Davies, Doyle, Eklund, Englert, Miller, Robson, Soler, St Denis, White; 24.6 RAs, 28.0 RSs, 7.0 support, £15.7m grants; 1120 journal articles

The particle physics experimentalists have made major contributions to the discovery of the Higgs (leading to the 2013 Nobel Prize) and the opening of new frontiers by the ATLAS and LHCb experiments. **Doyle** led ATLAS publications in this period and **Britton** leads GridPP. Particularly significant were: studies of the ttH channel along with top and jet production, the Higgs to bb decay channel and the combined Higgs results, as well as final limits from CDF. LHCb work has focused on two-hadron decays of B and D measuring the Bs to KK lifetime and studying CP-violation in D decay. On the theory side we have world-leading results in lattice QCD: parameters of QCD and hadronic decay rates needed to over-constrain the Standard Model. Calculations are being done on STFC's £15m DiRAC facility for which **Davies** chairs the Project Management Board. Phenomenology is closely tied to the experimental programme at LHC. We have focussed on predictions of realistic GUT models and improved calculations of QCD effects. Theory-experiment collaboration is expanding in Higgs and top physics for the future. The GLADD enables us to lead UK involvement in the ATLAS hardware upgrade (**Buttar** is UK lead) and vertex locator developments for LHCb (**Eklund** leads). We will continue to exploit the natural spin-offs from silicon detectors e.g. through Medipix. We also have significant leadership roles in future neutrino factory developments (**Soler**).

c. People, including:
I. Staffing strategy and staff development

Our staffing strategy is closely-aligned with our research strategy: to strengthen a diverse and balanced portfolio at the international leading-edge, without compromising our student learning experience. We also promote a School culture that nurtures new research talent such that all can develop to international leadership. Three leadership appointments (**Barnett, Harvey, Stamps**) since 2008 have been augmented by four promotions to professorships in line with our succession strategy (**Hendry**, now Head of School; **Ireland**, now research group leader of NP; **Woan**, now research group leader of AA; **Buttar**, heading ATLAS upgrade work in PP). We have made appointments at lecturer level (**Englert**, **Robson**, **White**, PP; **Hild**, **Martin**, IGR; **D. Maclaren**, MCMP; **Sokhan**, NP; **Croke**, **Taylor**, OPT) and **Eklund**, PP, at reader. Since 2008 our undergraduate numbers have grown to over 500FTE with an increased entry tariff, allowing us to add an extra specialist University Teacher (UT) to our existing three UTs to reduce teaching/administrative loads for research-active staff whilst improving the management of teaching. Research-active staff undertake an average of 27 lectures annually. Our School is housed entirely in the Kelvin building: staff are co-located with their research group and secretarial support. We have a total of 35.6 FTE of administrative, technical and IT support in the School, one third of which is recovered on research grants.

Career Development Support

Research Assistants. Recognition of the important role of RAs has increased significantly since 2008. Through a specially tailored formal annual Performance and Development Review (P&DR) with their line manager, they are expected to take an active part in planning their career progression and setting objectives for the year ahead. Promotion criteria are openly published (15 promotions since 2008). RAs undertake limited teaching duties (no more than 6 hours per week) with bespoke training provided to develop skills in this area. RAs are also able to attend courses offered to ECRs. The University of Glasgow runs an annual Research Staff Conference, well attended by members of our School, with talks on research careers, applying for fellowships, identifying funding opportunities and outreach activities. Within the School we have an RA forum which discusses issues relevant to RAs, and provides feedback to the periodic staff meeting. An RA representative (**Hannah**) attends the School Management Team every quarter.

Early Career Researchers. New staff normally undergo a three-year probationary period with annual targets in research, teaching and administration agreed with the Head of School and a mentor who is not a member of their research group. Teaching loads are built up gradually over the three years with the aim of gaining experience in different areas of the School curriculum. A cap on teaching duties is in place for those on personal fellowships. All ECRs undertake the University of Glasgow's New Lecturer Programme which leads to a Postgraduate Certificate of Academic Practice. A very successful multi-day College Crucible event held for ECRs includes externally-run sessions on research creativity, pitching a proposal and preparation of high-impact journal articles and is designed to encourage interdisciplinary collaboration across the College. A key objective during the probationary period is to obtain a research grant, but a 'start-up' fund of £6k is provided to all new staff from School endowments. The College also has a small equipment fund, awarding £80k to our ECRs in the last year.

Established Staff. The annual P&DR process involves appraisal by the Research Group Leader or, for professors, the Head of School, with assessment against published performance criteria (research outputs, funding, RS supervision, indicators of esteem, knowledge exchange and internationalisation activities) and individual SMART objectives agreed the previous year. Individuals are encouraged to plan their career progression and identify training and development needs. The School has run a transparent workload model for many years that is valued by staff as a fair means of apportioning tasks and responsibilities. We also have clear and published criteria for promotion, informed by output from the review process above and requiring external references for reader and professorial grades. Fifteen staff from the School have been promoted since 2008.

Concordat to Support the Career Development of Researchers. The 7 principles of the Concordat are strongly embedded in School and University practice, through the Code of Practice for the Management of Research Staff. The University of Glasgow's Concordat action plan was

most recently reviewed and updated, following feedback, in November 2012. We have an open recruitment process around an advertised job description with standard elements for each grade level. Open-ended contracts are the norm. Good practice on authorship and IP ownership is implemented. Specific School practice for RAs is summarised above.

Personal research fellowships won by staff in open competition. The table summarises current externally-funded competitive fellowships held by staff being included in this return.

Funder	Fellowship Scheme	Fellow	Group	Dates
Royal Society	URF	Buckley	PP	2012-17
Royal Society	URF	Martin	IGR	2011-16
Royal Society	Dorothy Hodgkin	Van Veggel	IGR	2013-17
Royal Society	URF	Hannah	AA	2013-18
EPSRC	Career Acceleration	D. Maclaren	MCMP	2010-15

In addition, research staff currently hold Royal Society Isaac Newton fellowships (Zhang, Fan), Alexander von Humboldt Feodor Lynen fellowship (Knue) and Royal Commission for the Exhibition of 1851 fellowship (Russell). **Davies**, **Padgett** and **Rowan** hold Royal Society Wolfson Research Merit Awards (3 of the 27 current physics holders in the UK). Leadership fellowships worth £385k have been awarded by the University of Glasgow to **Buckley**, **Hannah**, **Martin** and Messenger.

International staff. We aim to recruit staff from the widest possible international pool. Of 15 academic staff appointed since 2008, 7 have been non-UK nationals: **Croke**, Ireland; **Eklund**, Sweden; **Englert**, **Hild**, Germany; Laiho, US; Loos, Netherlands; **Stamps**, Australia). 34% of our total staff under research and teaching headings (41 of 121) are non-UK nationals. SUPA provides international visitor funding; £22k has been awarded since 2011 for 8 visiting scholars to the University of Glasgow from the USA, Germany, India, Italy and Russia. Of the 13 staff who have left since 2008, 6 were retirals, 3 moved to faculty positions elsewhere (Laiho to Syracuse, New York; Parkes to a chair in Manchester; Stockinger to Dresden) and 4 to other positions (Campbell to a staff position at Fermilab, Chicago; Kaiser on secondment to the International Atomic Energy Authority, Vienna; Loos to Principal Scientist, Dutch State Mines; Rosner on leave to Director of research at the FAIR facility, GSI, Darmstadt).

Equality and Diversity. Led by **Fletcher**, we obtained IOP Juno Champion status in 2011, the first School in Scotland to do so and 5th in the UK. In 2013 we obtained Athena Swan silver. We have six female academic staff (+ one UT) in the School, including two female professors, with one (**Rowan**) a member of the School Management Team. As evidenced by these awards, we operate good practice in staff development (several elements of which are described above), have School procedures for monitoring bias in our teaching outcomes and recruitment of RSs, RAs and staff and have an action plan for ongoing improvements. Evidence suggests that the University of Glasgow is now among the best in sector for pay equality following transparent 'zoning' of professorial pay in 2012. Our staff are significantly more positive than the Russell Group average on job satisfaction and career development and School integration/support (Vitae CROS and PIRLS surveys 2013).

c. II. Research students

RS numbers have been rising steadily in the School since 2008. We now recruit typically 25-30 PhD students a year; 10 from STFC and 6 from EPSRC doctoral training accounts, others funded by SUPA prize studentships (3 per year on average), College and University scholarships (2-3 per year on average) and other sources including industry, the EU and government scholarships (e.g. China, Malaysia, Portugal, Turkey). Students apply through the College Graduate School. Students benefit from access to the SUPA pooled postgraduate course programme with a mix of technical courses and core skills (such as advanced data analysis, presenting and writing), delivered via broadband video links to the 8 sites. There are over 60 courses across 7 research themes. RSs are required to take 40 hours of technical courses and 20 hours of core skills during the first two years of their PhD, and pass the assessment at the end of each course. Students also attend induction and networking events and specialist lectures from SUPA distinguished visitors. The University of Glasgow also has an extensive researcher development programme attended by our RSs, encouraging career planning and including initiatives such as the annual 'three minute thesis'

competition. Within the School RSs benefit from an extensive seminar and colloquium programme and are required to provide summaries of colloquia attended in their first year report.

We operate standard good practice in allocating first and second supervisors to RSs with the first closely associated with the project and the second providing more general support. RSs have a budget of £1500 for travel to attend conferences/schools and a more general budget is provided to each research group for activities in support of RSs. The School currently has £190k of STFC funding for RS long-term attachments.

Students write a report every year, competing for £1000 prizes, and have a progression interview with a member of the Graduate School committee and their second supervisor. In their third year RSs give a short talk to the rest of the School as part of a set of special School colloquia and submit a thesis plan. RSs are required to submit a thesis before the end of their fourth year, with an exceptional case required for an extension. Our 4-year completion rate for the most recent 2009 starting cohort is a healthy 84% (national average 70% [HEFCE]). Submitted theses are examined by a viva with an external examiner, internal examiner and convener, all independent of the project. 90% of our students were satisfied with their PhD experience (HEA postgraduate research experience survey 2013), compared to a sector average of 84%.

d. Income, infrastructure and facilities

The School is underpinned by sustained RCUK funding, currently £230k per FTE per year, placing us in the top five of the Russell Group. Since 2008 the School has benefitted across all of our groups from significant investment in specialist equipment and infrastructure, which now has a total value (for insurance) of £21.5m.

i) Provision of, and investment in, specialist infrastructure and facilities

The School houses:

• An aberration corrected electron microscope (JEOL ARM 200FCS, £2.4m), that has been uniquely customised in collaboration with manufacturers JEOL and Gatan. It incorporates state-of-the-art high-speed X-ray and electron spectrometry for atom-resolved chemical mapping, and a bespoke detector assembly for imaging magnetic media. The latter enables world-leading sub-nm resolution of magnetic structure, an area in which Glasgow is pre-eminent. Our sample growth capabilities were recently expanded by a £400k (**D. MacLaren**: EPSRC CAF) pulsed laser deposition tool, enabling new explorations into advanced functional materials, especially complex oxides. The combination of our Kelvin Nanocharacterisation Centre (KNC) and the College James Watt Nanofabrication Centre gives the University of Glasgow a world-class fabrication, characterisation and materials analysis capability. Whilst primarily for research, over 20 companies and institutions have made use of the KNC facilities under contract since 2008.

• A 10m prototype gravitational wave detector, which we have developed to a mature level of operation over the past ten years in clean room facilities. This has provided an increasingly important world-leading capability for testing novel technologies for interferometry and ultra-precision displacement measurements. Since 2008 this has been directed towards upgrades to Advanced LIGO. Further developments going beyond the quantum limit are also underway (**Hild**: ERC £1.2m). During 2005-11 we used a £1.5m investment to refurbish and equip a clean laboratory with a suite of state-of-the-art materials characterisation facilities. This has enabled us to build the precision opto-mechanical hardware needed for the Advanced LIGO suspension and the LISA Pathfinder mission. We also doubled clean room capacity, including the provision of precision micro-manipulators and ultra-clean assembly with STFC/ESA investment, for making space-qualified flight hardware for LISA. Development of technology for future missions is ongoing with ESA contracts. Our capabilities have enhanced interaction with industry, for example local company ClydeSpace, developing components for CubeSat.

• The biggest Tier 2 computing centre in the UK, part of the worldwide Grid for particle physics. £400k of University investment enabled us to commission a new computing room in 2009, doubling our previous capacity to over 4000 CPUs and 1300 Tbytes of disk space (£1.2m STFC funding). This is a key resource for experimental particle physics, but also used much more widely, e.g. by bioinformatics. The University of Glasgow has committed to a £700k upgrade of the centre during 2014.

• Extensive detector development facilities that have enabled us to contribute to building and commissioning the silicon central tracker for ATLAS and the vertex locator for LHCb in 2008 (£1.1m STFC-funded equipment), as well as to take a leading role in the particle identification systems for the CLAS 12 experiment at Jefferson Lab and the PANDA experiment at FAIR (£150k STFC/EU investment). Spin-offs from this work include retinal micro-electrode and medipix chip developments as well as a muon tomography facility being built with investment from the National Nuclear Laboratory (£1.8m). In 2012 £400k SUPAII investment in GLADD enabled upgrade to 50m^2 of "class 100" clean room for R&D for LHC upgrades and spin-offs.

• Fully-equipped space for our experimental programme in quantum optics, structured light for imaging and atomic control with laser sources from ultra-violet to mid-infrared and low-light and high-speed camera systems. A new capability is a laboratory for computational and biomedical imaging set up by **Harvey** with £200k of University/SUPA II investment for lab refurbishment and housing £700k-worth of equipment funded by EPSRC, NHS, TSB and industrial support.

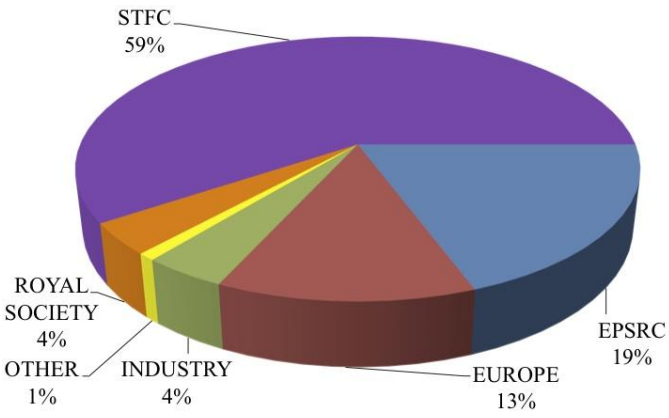
Additionally, a major programme (>£600k) of teaching space refurbishment in 2007-11 has given us a much more flexible, and now well-used, space for meetings and workshops with provision for lectures, posters/exhibitions and catering in one area. Leveraging GridPP investment of £100k we upgraded our School IT network to 10 Gbits in 2012 with a 10Gbits external connection.

As is clear in Section b, expertise from the School has had significant impact in making the case for, and developing, major international research facilities. Further UK examples include STFC's DiRAC High Performance Computing Facility and EPSRC's SuperSTEM facility at Daresbury.

ii) Future Investment Plans

In addition to the enormous potential for our staff to contribute to, and benefit from, future investment in major international facilities, as described in Section b, the School is planning significant investment in our local research environment over the next decade – as the University of Glasgow embarks upon its most ambitious building programme in 150 years with the acquisition of the 14-acre Western Infirmary site adjacent to the current campus. Advanced discussions are already underway concerning two specific areas of investment. The first concerns a flagship "Big Data" centre that would build upon our UK leadership of the Grid, Computing Science expertise and the strong potential for multidisciplinary research with Engineering and Biomedical Sciences, alongside exploitation of emerging new income streams from government and industry. The second opportunity would build upon the School's leadership of the IMPP through significant further investment in the key emerging technology of quantum measurement and quantum information. Again, our plans are focused on a multidisciplinary approach, with substantial government and industrial engagement. While these initiatives will also have a strong SUPA-wide dimension, the University of Glasgow will take a leadership role in both of them.

iii) Information on research funding portfolio, including future plans



Between RAE2008 and REF2014 we have achieved a doubling of our average research income per annum. The total of active grants during FY2012-13 was £49.6m, split according to sources in the pie chart. STFC income predominates, underpinning our strengths in AA, IGR, NP and PP areas; we are in the top 10 funded physics departments by value in the UK [STFC: grants on the web]. Further we have successfully trebled our EPSRC funding for MCMP and OPT (to over £2.5m per annum) and doubled our EU income (to £700k per annum) since RAE2008. We have already secured a further increase in EU funding with new ERC starter (**Hild**) and advanced (**Padgett**) grants. With new appointments (particularly the leadership appointments of **Barnett** and **Harvey**) we anticipate significant further expansion of our EPSRC portfolio and industrial income. Our research portfolio has also been enhanced by £7.5m of investment from the Scottish Funding Council and the University of Glasgow under the SUPA II agreement.

Our RS population has increased markedly (97.4 in 2012-13 vs. 70.5 in 2008-9 [HESA]) with increased studentship funding coming from industry (8 in 2012-13 vs. 2 in 2008-9) and international government sources (7 in 2012-13 vs. 0 in 2008-9). We will leverage further increases from these sources in future, building on the College's ongoing yearly investment of >£1m in international student fee reductions and 50% funding of industrial PhDs. We plan to fund 20 EngD, CASE and Industrial PhDs within the School before 2019 from CENSIS, CDTs and other sources. Our RA population (78.0 plus 5 fellows) has increased slightly since 2008. We plan to increase this further in future by greater engagement with EU funding streams.

iv) Usage of facilities not supported by the Research Councils

We show here the University of Glasgow 'share' of running costs of facilities used by us abroad and provided by non-UK funding sources, either as the result of an explicit competitive bidding process or implicitly through our expertise being sought in international collaborations. The figures amount to additional 'income' of over £3m per year, as detailed below:

Group	Facility	Total cost	University of Glasgow share	Cost of University of Glasgow share
AA	ISSI Bern	£12k per workshop	5 workshops led	£60k
	RHESSI	$2m per year	10% by publications	$200k per year
IGR	LIGO	$47.3m per year	5% by members	$2.4m per year
	GEO	350k€ per year	20% by members	70k€ per year
NP	Jefferson Lab	$5.7m per year	5% by authors	$285k per year
	Olympus, DESY	£3m per year	5% by authors	£150k per year
	MAXLab Lund	£400k per year	5% by authors	£20k per year
	Mainz	£0.5m per year	5% by authors	£25k per year
PP	DEISA computing	2 million core-hours	50% by users	1 million core-hours
	Fermilab	$280m per year	0.5% by authors	$1.4m per year

v) Information on consultancies and professional services

Since 2008 the School has provided consultancy/professional services to 25 companies, earning over £150k. Key companies/organisations were Arcelor Mittal, AMEC, Coherent, DSTL, Freescale, National Nuclear Laboratory, Noventa, Selex and Texas instruments.

e. Collaboration and contribution to the discipline or research base

i) Research collaboration

Our staff in the AA, IGR, NP and PP groups work in major international collaborations ranging in size from 20-3000 members and exploiting international facilities. We lead activities within these collaborations all the way through from detector design to physics analysis. Examples of these leadership roles during 2008-13 are: **Annand**, coordinator of the BigBite upgrade at JLAB and project leader of 4 experiments at JLAB, MAMI and Max-Lab; **Britton**, GridPP project leader and member of European Grid Initiative Project Management Board; **Buckley**, convenor of ATLAS Collaboration Monte Carlo generators working group; **Buttar**, project leader of the ATLAS-UK Upgrade programme; **Davies**, co-lead of HPQCD Collaboration and chair, Project Management Board of STFC's DIRAC facility; **Diver**, member of the EPHRAT steering group; **Doyle**, chair of the ATLAS Publications Committee; **Eklund**, project leader, LHCb VELO project; **Fletcher**, member of the ATST Science Working Group; **Hammond**, chair LIGO charging sub-group; **Hough**, chair of Gravitational Waves International Committee; **Ireland**, chair of the Hadron Spectroscopy Working Group, then chair and spokesperson, CLAS collaboration; **Livingston**, member of Crystal Ball Steering committee, Mainz; **Kontar,** CESRA board member; **I. Maclaren**, member of the SuperSTEM Management Team; **Miller**, member of the LHC Higgs cross-section working group; **Robson**, head of Offline, CDF; **Rowan**, member of LIGO programme advisory committee, LIGO international oversight committee, ASPERA/ApPEC science advisory committee; **Seitz**, UK representative on Hadron Physics 3 governing board; **St Denis**, head of Offline, CDF; **Strain**, chair of LIGO Advanced Interferometer Configurations Working Group; **Woan**, member of LOFAR UK Management Committee, e-MERLIN Project Management Committee and co-chair LIGO Continuous Waves Investigation Group. The School provides flexibility to support such formal

leadership roles and responsibilities through explicit recognition in our workload model. The School also encourages staff to seek external funding for fixed-term buy-outs from teaching and administration. Recent examples include: CERN Associateships (**Doyle**, **Eklund**), Fermilab Associateships (**Robson**, **St Denis**), an STFC Senior Fellowship (**Doyle**) and Royal Society/Leverhulme Senior Fellowships (**Barnett**, **Davies, Padgett**).

The work of our OPT and MCMP groups is also highly international and strongly collaborative, even if links are not as formal. Since RAE2008 members of each of these groups have co-authored publications with staff in over 100 institutions across 5 continents. Long-term industry partnerships are also important; examples include Gatan, JEOL, Seagate and Shell.

All groups are strongly involved in EU programmes. AA: *RadioSun*, FP7 IRSES with China/Russia; *HESPE*, FP7 project; *F-CHROMA*, FP7 network (**Fletcher** coordinates). IGR: FP6 network *ILIAS*; FP7 network *Einstein Telescope Design Study* and follow-on *ELiTES* exchange scheme between EU/Japan. MCMP: *PrecHiMa* European Commission Research Fund; *IFOX* large-scale integrating project. NP: *HadronPhysics2* and *HadronPhysics3* Integrated Infrastructure Initiative (Rosner on Executive Board). OPT: *HIDEAS*, FP7 STREP; *PHORBITECH*, FP7 FET Open programme. PP: *European Grid initiative*; *European High Intensity Neutrino Facility design study*; *AIDA*, advanced European infrastructures programme (**Soler** deputy coordinator); *Strongnet*, FP7 network.

SUPA has nurtured further international collaboration. For example, the University of Glasgow-led International Max Planck Partnership (IMPP), on Measurement and Observation at the Quantum Limit, will promote scientific cooperation, including joint PhDs between the Universities of Glasgow, Strathclyde, St Andrews, Heriot-Watt and Edinburgh and the Max Planck Institutes in Hannover, Erlangen, Garching, Dresden and Stuttgart.

ii) Information on support for and exemplars of interdisciplinary research

Interdisciplinary research has grown since RAE2008 supported by College/University initiatives. ECRs are strongly encouraged to participate in the College Crucible programme designed to develop their creative ideas. In addition **D. Maclaren**, **Hild**, **Seitz** and **White** have won selection to the competitive Scottish Crucible. Examples of current interdisciplinary work (with joint grant/paper) include: OPT with clinicians to develop techniques for breath analysis and fluorescence labelling of cancerous tissues and for retinal oximetry, with chemists for the optically directed growth of inorganic structures, with mathematicians for interpretation of 3D scenes; MCMP with chemists on catalysis, photovoltaics and molecular oxides, with engineers on diamond electronics and advanced lithography, with medicine on MRI contrast; AA with biologists on detecting airborne bacteria; IGR with engineering to develop gravimeters, with medical technologists on imaging diagnostics; NP with clinicians on radiotherapy; PP with engineers on detector development, with earth scientists on grid computing, with computer scientists on combinatorics for networks.

iii) Information on how research collaborations with research users, including industry users, have informed research activities and strategy

Our long-term strategic plans are focused around our core expertise in each area and RCUK priorities (which we influence, see e(iv)). Within this programme we increasingly see opportunities for interdisciplinary activity and knowledge exchange, as linkages grow across the College and beyond. Often such activity has strong input from users. The CENSIS initiative is a good example, being shaped by industrial partners from its inception. In the future our External Liaison Team will further enhance the role of industry and other end-users in our strategic investment decisions.

iv) Indicators of esteem

Fellowships of learned societies: We have 2 FRS (**Barnett, Hough**) and 13 FRSE (**Barnett, Chapman, Davies, Doyle, Hendry, Hough, Padgett, Rowan, Stamps, Strain** + honorary Brown, Saxon and Rosner on leave). Our staff have also been elected FRSA and FIGRG (both **Hough**), FAPS (**Hough, Rowan**), FOSA (**Barnett, Padgett**), FSPIE (**Padgett**) and FIEEE (**Chapman**). **Strain** is a member of the Max Planck Society.

Personal fellowships: During the REF period Royal Society Wolfson Merit Awards have been held by **Barnett, Davies, Padgett** and **Rowan**. **Buckley**, **Hannah** and **Martin** hold RS URFs, **D. Maclaren** holds an EPSRC CAF and **van Veggel** holds a RS Dorothy Hodgkin fellowship.

Leadership roles in research councils/learned societies/professional bodies: STFC: **Rowan** was deputy chair, PPAN Science Committee (2009-11) and a core member of Science Board (2011-12); **Britton** and **Ireland** are non-core members; **Buttar** chairs NuStar oversight committee and chaired PPRP 2009; **Davies** is on PPAP; **Seitz** and **Robson** are on PPRP; **Soler** on PPGP; **Fletcher** chairs Solar Studies sub-panel; **Ireland** chaired Nuclear Physics Grants panel (2010-12). **Barnett, Padgett** and **Stamps** have served regularly on EPSRC panels and Padgett has chaired EPSRC responsive mode panel 4 times. **Barnett** chaired the RSE sectional panel for physics (2010-13) and was succeeded in this role by **Davies**. **Rowan** was elected to RSE Council (2010-13) and was president of the BSA physics & astronomy section (2012). **Hammond** and **Hild** were elected to the RSE Young Academy. **Davies** chaired the IOP Diversity committee and sat on IOP Council (2007-11). **Diver** chairs the IOP Plasma Physics Group; **Ireland**, the Nuclear Physics Group (2008-11), **I. MacLaren,** the Electron Microscopy and Analysis Group and **Miller** was secretary of the IOP Particle Physics Group (2009-12). **Macgregor** chaired the IOP Nuclear and Particle Physics Division (2009-12) and is chair-elect of the European Physical Society (EPS) Nuclear Physics division (2013). **Hendry** is chair-elect of the IOP in Scotland. **Doyle** chairs the Institute for Particle Physics Phenomenology steering board and the SUSSP management committee. **Fletcher** is vice-president of the IAU Commission on Solar Activity and secretary of the RAS Council. **Harvey** chairs the OSA Fraunhofer Prize Committee. **Hough** is SUPA CEO and a member of the Scottish Science Advisory Council, sits on the EPS Executive Committee, the European Science Foundation PESC core committee and on IOP Council.

Prizes and Awards: **Barnett** won the IOP Dirac Medal (2013); **Davies** won the IOP Nuclear and Particle Physics Division Prize (2011); **Fletcher** gave the RAS Jeffreys prize lecture (2011); **Hannah** won the RAS Fowler prize for geophysics (2013); **Hough** won RSE Gunning Victoria prize (2008); **Padgett** won the IOP Optics and Photonics Division Prize (2008) and Young Medal and prize (2009); **Robson** won the RSE/Sir Thomas Makdougall Brisbane Medal (2013); **Stamps** was IEEE Distinguished lecturer (2008). **Davies**, **Hough** were awarded OBE and **Rowan** MBE.

Journal editorships: **Barnett**, divisional associate editor of Phys. Rev. Letters; **Chapman**, editorial board, Materials Science and Engineering Reviews; **Courtial,** topical editor, Journal of the Optical Society of America A; **Barnett**, **Harvey**, **Padgett,** editorial board of the Journal of Modern Optics; **Padgett**, editorial board, New Journal of Physics; **Fletcher**, editorial board, Solar Physics; **Stamps**, editor of 'Solid State physics' and associate editor, IEEE Magnetics Letters.

Invited talks: Since 2008 our staff have given more than 300 invited talks at international conferences and external institutions. Recent highlights include: **Buttar**'s Soft-QCD review at the Hadron Collider Physics Symposium (Kyoto, 2012); **Davies**' Lattice-QCD review at the Lepton-Photon meeting (Stanford, 2013); **Doyle's** review of Higgs spin/couplings at Higgs Hunting meeting (Orsay, 2013); **Fletcher's** review of Flare Science with ATST at the AAS Solar physics meeting (Montana, 2013); **Hild's** gravitational-wave detectors and **Hammond's** thermal noise reviews at the 9th Eduardo Amaldi conference (Cardiff, 2011); **Kontar's** high energy solar flares review at the International Symposium on Solar-Terrestrial Physics (Pune, 2012); **Macgregor's** review of MAMI research at the International Symposium on Lepton-hadron physics (Sicily, 2013); **Padgett**'s plenary lecture at SPIE Photonics West (San Francisco, 2013); **Stamps**' plenary lecture at the International Magnetism and Magnetic Materials conference (Phoenix/Scottsdale, 2011).

Conferences organised: Since 2008 we have organised over 40 meetings/workshops in Scotland with >30 participants. Highlights (chair, attendees) include: Baryons 2013 (**Ireland**, 150); International Conference on Optical Angular Momentum 2013 (**Franke-Arnold**, 100); ATLAS-UK Collaboration meeting, 2012 (**Buttar**, 190); IOP Nuclear and Particle Physics Division meeting 2011 (**Macgregor**, 450); UK Plasma Physics 2011 (**Diver**, 93); UK National Astronomy meeting 2010 (**Fletcher**, **Hendry**, 550); International Conference on Vertex Detectors 2010 (**Eklund**, 75); EU COST meeting, Micromanipulation by nonlinear nanophotonics 2009 (**Padgett**, 100); International Conference on Position Sensitive Detectors 2008 (**Buttar**, 200). We have organised graduate schools in LHC physics (SUSSP65 2009, SUSSP69, 2012) and the STFC Introductory summer school on astronomy 2011, each with ~100 participants. Our staff have also chaired the organisation of major international conferences outside Scotland. 2013 highlights include: **Harvey**, General Chair, OSA conference on Computational Optical Sensing and Imaging (Arlington, 2013); **Rowan**, SOC Chair, 10th Eduardo Amaldi conference (Warsaw, 2013).