**Institution: Durham University**

**Unit of Assessment: 9 - Physics**

## a. Overview

Durham Physics is the largest of the seven Departments and Schools that constitute the Faculty of Science at Durham and is a thriving centre for both education and research. It is one of the largest physics departments in the UK, ranked #3 in the 2014 Complete University Guide subject league tables. The permanent academic staff has grown steadily and is now comprised of 32 Professors, 12 Readers, 8 Senior Lecturers and 22 Lecturers. Three current and two emeritus staff are Fellows of the Royal Society. We host 6 Senior and 12 Junior Research Fellows, 69 Post-Doctoral Research Assistants (PDRAs), 139 postgraduate research students, 24 technical research support staff and 24 Visiting Professors. In addition, there are 3 Teaching Fellows, 6 technicians supporting teaching and 17 secretarial and administrative staff.

The stable and stimulating environment resulting from the long term commitment of more senior staff to the department and vice versa enables young and talented academic staff to deliver internationally leading research. The impact of our work is exceptional. In the review period, staff published more than 2150 papers which have been cited over 59200 times. For example, the Astronomy group in Durham was ranked 4th in the world (and 1st in Europe) based on our citation impact in the most recent THES analysis published in 2010 and has six researchers listed in ISI's "Most Highly Cited". Over the past five years, the top 1% of our astronomy papers are in the top 0.1% of the 146,000 papers published world wide.

We currently teach 556 undergraduates through a combination of 4-year MPhys and 3-year BSc single honours degrees and 4 year MSci and 3 year BSc interdisciplinary degrees under our Natural Sciences programme. Teaching within the Department follows a research-led philosophy from year 1, and half of the fourth year comprises an individual research project.

## b. Research Strategy

The Department's research strategy aligns closely with the overarching University strategy which includes research related aims of: transformative research, the highest standards of research-led education, international partnership building and sustainability. We aim to exploit the subject-specific strengths of our 5 Research Sections (see Table 1) and the collaborative opportunities that arise from: a strong and stimulating Departmental research culture, a long tradition of local interdisciplinary research collaborations with other departments in the Science Faculty (exemplified by joint grants such as the EPSRC programme grant "A quantum gas of Ultracold molecules", £1.1M with Chemistry) and a wide range of national and international strategic partnerships. All five Research Sections are extensively networked in collaborations around the world, for example via EU funded networks such as COHERENCE, CosmoCOMP, DYNACOP, Invisibles, LHCPhenonet and MCNet.

Two of the University's nine Research Institutes (URI) are wholly based in Physics, the Institute for Particle Physics Phenomenology (IPPP) and the Institute for Computational Cosmology (ICC) which together make up the Ogden Centre for Fundamental Physics. The other URI act as catalysts and foci for multidisciplinary projects across the Science Faculty. We provide the leadership (Girkin) of the Biophysical Sciences Institute (BSI) and have strong involvement with the Durham Energy Institute (DEI), the recently created Institute for Advanced Research Computing (iARC), the Wolfson Research Institute for Health and Wellbeing (WRI) and the Institute for Advanced Study (IAS).

The Department also leads a number of interdisciplinary research centres; the Centre for Advanced Instrumentation (CfAI), which is the UK's largest university-based instrumentation group for ground-based astronomy, the Centre for Materials Physics (CMP), the Centre for Particle Theory (CPT), the Centre for Soft Matter (CSM) and the Durham X-ray Centre. The Joint Quantum Centre (JQC)

links staff working on quantum physics in the Physics and Chemistry Departments in Durham and Applied Maths and Engineering at Newcastle.

**Table 1: Research Sections and Strategic Aims**

| Research Section (Members) | Abb | Strategic Aims |
|---|---|---|
| Advanced Instrumentation (Love, Allington-Smith, Girkin, Morris, Myers, Saunter, Sharples, Wilson plus 17 PDRAs, 18 Phd students and 10 computing and engineering support staff. Kellerer is a Research Fellow and Robertson is a Professorial Fellow.) | CfAI | Design and development of novel instrumentation based on cutting edge technologies for application across a wide range of disciplines including astronomical instrumentation, biophysics, remote sensing and fusion diagnostics. |
| Astronomy and Astrophysics (Smail, Alexander, Baugh, Bower, Brown, Chadwick, Cole, Done, Edge, Eke, Frenk, Jenkins, Lacey, Li, Lucey, McComb, Roberts, Shanks, Theuns, Ward plus 22 PDRAs, 46 Phd students and 7 research support staff. Aird, Cai, Gandhi, Gao, Guo, Landt, Massey, Norberg, Rovilos, Russell, Swinbank, Wang are Research Fellows and Sir Arnold Wolfendale is an emeritus professor.) | Astro | Study of a wide range of fields including the observational, theoretical and instrumentation aspects of astronomy. Examples include numerical studies of galaxy formation, large- structure and the nature of the cosmic dark matter, and observational studies of the formation and evolution of galaxies, black holes and active galactic nuclei, the evolution of larger-scale structures in the universe and tests of cosmological theories. |
| Atomic and Molecular Physics (Gardiner, Adams, Carty, Cornish, Hughes, Jones, Potvliege, Weatherill plus 9 PDRAs and 24 Phd students. Mason is a Research Fellow and Flower is an emeritus professor.) | AtMol | Experimental and theoretical study of atom-light interactions, ultracold molecules, trapped atomic and molecular gases and Bose-Einstein condensates. |
| Condensed Matter Physics (Clark, Abram, Atkinson, Brand, Bromley, Cross, Fielding, Gidopoulos, Halliday, Hampshire, Hatton, Hindmarch, Hunt, Kusumaatmaja, Lancaster, McLeish, Mendis, Monkman, Staykova, Szablewski, Tanner, Terry, Voitchovsky plus 2 Teaching Fellows, 9 PDRAs, 23 Phd students and 7 research support staff. Bloor and Chamberlain are emeritus professors.) | CMP | Study of a wide range of theoretical and experimental physics including Condensed Matter Theory; Nanoscale Science and Technology; Superconductivity; X-ray Scattering and Magnetism; Organic Electroactive Materials; Photonics; Semiconductors, Electroceramics and Crystals; Muon Physics and Soft Matter & Biological Physics. |
| Elementary Particle Theory (VV Khoze, Abel, Andersen, Boehm, Duhr, Franco, Glover, Krauss, Lenz, Maitre, Martin, Maxwell, Pascoli, Pecjak, Richardson, Spannowsky plus 12 PDRAs, 27 research students. Degrande, Mariotti, Wiebusch are Research Fellows, VA Khoze is a Professorial Fellow.) | IPPP | The study of the building blocks of all matter in the universe and of the fundamental forces that operate between them and to develop new theoretical ideas aimed at addressing key science questions that are experimentally accessible such as: What is the origin of mass? Why is there more matter than antimatter in the universe? Is there a unified theory of all particle interactions? |

**Process:** Our strategy is captured in an annually-updated 5 year plan, to which all academic staff are invited to contribute. This is monitored by our Senior Management Committee and centres around 8 key challenges; Improving Research Performance, Improving Students Education Experience, Becoming a Top 50 World University, Increasing Links with Industry and other Partner Organisations

to improve research, teaching and employability, Overcoming Constraints, Retaining and Recruiting World Leading Academics, Preparing for the Future Direction of Science at Durham and Improving Diversity & Equality. The Faculty research strategy is determined by the Pro-Vice Chancellor (Science) with input from the Faculty of Science Research Advisory Group chaired by the Deputy Head of Faculty for Research. Overall research strategy for the University resides within the portfolio of the Pro-Vice Chancellor (Research) (McLeish). Within the Department, our research activities are overseen by four main committees (see Table 2) which report directly to the Board of Studies (BoS), the Department's top level decision-making body. Research Centres and Institutes report to the Faculty Research Committee and University Research Committee respectively.

| **Table 2: Committees - Members** | **Committee Remit** |
|---|---|
| *Senior Management Committee* (**SMC**) - Head of Department (HoD), Director of Research (DoR), Director of Education (DoE), Facilities Committee Chair, Postgraduate Committee Chair, Research Section Heads, Senior Administrator | Advises HoD on education and research, budgets, staffing and strategy. |
| *Research Committee* (**RC**) - DoR, HoD, Research Section Heads, Institute Directors, Impact Champion, Research Administrator, Senior Administrator | Formulates/implements research strategy, coordinates funding applications, awards and research leave. |
| *Facilities Committee* (**FC**) - Chair, Service Managers, Academic Reps | Management and development of the facilities and workshops. |
| *Postgraduate Committee* (**PC**) - Chair, Research Section representatives, postgraduate administrator | Manages all aspects of the recruitment, training, monitoring and welfare of graduate students, allocates PhD funding. |

**Strategy:** Our current areas of focus and strategic aims closely follow those laid out at RAE 2008, with adjustments where staffing changes or research developments have led to new opportunities. Our specific aims at RAE 2008 were to:

- *build research strength necessary to be world leaders in our selected areas.* We have continued to be able to attract new staff of the very highest calibre (see staffing strategy below), strengthening and broadening our core research areas, and retaining them, e.g., through proactive use of the Wolfson Merit Award scheme. The University provides very competitive start-up packages to new academics, including helping to find positions for partners and is very supportive for the recruitment of Royal Society URF (e.g. Massey) or ERC grants (e.g. Norberg).
- *achieve our aims in a sustainable manner which secures the future development of the Department.* There has been planned renewal and growth in IPPP and CMP, enabling targeted recruitment to refocus our research on, for example, LHC physics and materials physics. In AtMol and CfAI, for example, we continue to build a critical mass of researchers. We are developing new research areas both within the UoA and across disciplines by, for example, exploiting strong synergies between research areas of the BSI and DEI.

Strategic goals we are working towards over the next five years include:

- **Research Quality:** Our primary goal is to ensure that every member of academic staff is publishing research which is internationally excellent in terms of originality, significance and rigour. This starts by recruiting top quality staff and then helping them to have the time and resources to produce excellent research. We ensure academic staff have sufficient time for quality research through workload management and through regular reviews of the quantity, modes of delivery and sequence of modules offered in our undergraduate programme. We have increased academic research time by means of Teaching Fellows funded through research grants and gaps in recruitment. Individual research plans and outputs are monitored via Personal Research Plans

(which form part of the Annual Staff Review process) and supported strategically via Research Leave and additional support for finishing PGR students. Another key element in our strategy is to enhance the quality of grant applications via internal peer review of the proposals, drawing upon the experience of those involved in the external peer review process. Junior staff are given close mentoring, especially for their first few grant submissions. Our dedicated Research Administrator helps us achieve the largest Research Grant Income within the University. The faculty enhances our grant income with, for example, matched funding for PhD students and more than £3M for equipment, while the EU-University funded DIFeREns scheme operated by the IAS funds several junior and senior research fellows in the Department.

- **Funding:** Nobody can reasonably doubt that a difficult period lies ahead, and we will be more resource limited than recently. We have recognised the need to diversify research income streams, which had traditionally come largely from research council sources and have already significantly increased funding income from non-research council sources, particularly the EU. It remains our goal to further broaden and diversify our income streams.
- **Infrastructure:** We need to maintain and enhance our excellent research infrastructure, expanding our suite of advanced equipment, fully exploiting the advanced construction facilities at NETPark (with which, for example, CfAI successfully completed its contract with Surrey Satellites Technology Ltd to deliver the diamond-machined NIRSpec integral field unit which will be launched on the James Webb Space Telescope in 2018), and by developing new low-vibration, low noise laboratories for experiments in precision metrology.
- **Space:** Our aggressive academic recruitment strategy coupled with success in attracting new grants (including ERC grants, an EU Fusion grant and EU/EPSRC training networks) has led to significant expansion. Our vision is now fixed firmly on a £10.4M new building, partly funded by donations and partly by the University. The internationally renowned architect Daniel Libeskind has been selected to design the new building with ground-breaking targeted for Autumn 2014. This new research facility is the cornerstone of our strategy for advancing Durham Physics to the very top level nationally and dramatically enhancing our profile internationally.
- **UG Teaching:** We are fully committed to the delivery of research led education at a first class international standard. This is exemplified by the high weight given to the research project undertaken in the final year of the MPhys degree when the student is embedded in a research group. Each year several UGs co-author papers in peer-reviewed international journals, e.g., Phys.Rev.B82, 104407 (2010), Appl.Phys.Lett.101, 023115 (2012), J.Phys.B45, 215005 (2012).
- **Doctoral Training:** We will continue to develop our suite of postgraduate training opportunities. The Durham Centre for Soft Matter led a successful consortium application (with Edinburgh and Leeds plus 18 industrial partners) for an ESPRC Centre for Doctoral Training in Soft Matter and Functional Interfaces to run from 2014 to 2020 in the first instance. The value of EPSRC and partner funding is £9.3M. Soft Matter scientists will work within interdisciplinary teams on molecular approaches to advanced materials including polymers, colloids, surfactants, self-assembled nanostructures, food science and coatings. PhD students will undertake a mini-MBA as well as their science research, in preparation for either industrial or academic research careers, and receive an international training experience through the global partnership in Soft Matter (including ESPCI Paris and the Duke/Chapel Hill MRSEC). We will also continue our successful leadership of EU training networks (e.g. CosmoCOMP, HiggsTools) where we benefit from the courses provided by the Durham Graduate School Training Team which won the THE Award for Outstanding Support for Early Stage Researchers in 2009.
- **Future Focus:** We aim to maintain and develop our core research activities by, for example, joining new Astronomy initiatives to enhance research output such as Pan-STARRS-2, the DESI (formerly BigBOSS) redshift survey or building and exploiting a panoramic, multi-object spectrograph for the VISTA telescope (called NG2dF). Other areas we plan to grow in future years include: *Fusion:* CfAI and CMP are partners in the CDT in fusion with York, and CMP have recently been awarded a major EU/ITER grant to maintain the European Fusion Energy Reference Laboratory

in superconducting materials in Durham. There is the potential to make Durham University a recognized centre for fusion related research in materials science by exploiting synergies with the DEI and the Engineering Department. *Cold ion beams:* The use of laser-cooled atoms as a high-brightness source for cold ions is one of the most exciting concepts to emerge in atomic physics over the past decade and we aim to establish a new experimental research activity using cold ion beams. It holds tremendous potential to impact nanotechnology (links to magnetism and spintronics in CMP) and biophysics (link with BSI). Currently there is only one group worldwide (NIST in the USA) starting activity in this area and there is considerable potential for intellectual property rights and spin-out in producing a new generation of focused ion-beam systems.

**c. People,including:**

**i. Staffing strategy and staff development**

Our staffing and support strategy has followed that laid out in our RAE 2008 strategic plan, which was to build research strength necessary to be world leaders in our selected areas. We have a general policy to recruit internationally and to appoint academic staff at lecturer level, seeking individuals with the potential to develop into world-leading researchers. When there has been an identified need to strengthen leadership we have appointed at senior level, for example McLeish to initiate and lead research in Soft Condensed Matter in 2008 and Girkin to a Chair in 2009.

The Department has enjoyed a period of steady and sustainable growth. Consistent with our overall strategy, we have built on existing strengths and expanded into new areas where these reinforce interdisciplinary research. New academic appointments since 2008 include Weatherill (AtMol), Massey, Norberg, Lacey, Li, (Astro), Girkin, Saunter (CfAI), Bromley, Dias, Fielding, Gidopoulos, Hindmarch, Kusumaatmaja, Lancaster, McLeish, Mendis, Staykova, Voitchovsky (CMP), Andersen, Boehm, Duhr, Franco, Lenz, Maitre, Pecjak, Spannowsky (IPPP). This sustained growth has gone in tandem with a relatively small number of staff leaving (for senior positions in the UK (e.g. Stirling) or returning to their home country) leading to an increase in the number of permanent academic staff from 56 in 2007 to 74 today. Our policy has resulted in a sustainable age profile: 4% of the staff are 25-34, 34% are 35-44, 31% are 45-54, 10% are 55-64 and 5% are aged 65+. 11% of the permanent academic staff are female which is comparable to the median figure of 11.5% from the 2013 IoP Statistical Digest of Academic Physics Staff in UK HEIs. Since 2008, a number of staff have won or held prestigious fellowships:

| | |
|---|---|
| **Fellows of the Royal Society** | Frenk, Glover, Martin, McLeish and Sir Arnold Wolfendale |
| **Royal Society-Wolfson Merit Award** | Frenk, Glover, Gregory (joint appointment with Mathematical Sciences, returned with UoA10), VV Khoze and Smail |
| **ERC Grants** | **Advanced**: Frenk, Glover, Smail. **Starting**: Fielding, Norberg. **Consolidating**: Pascoli. |
| **Royal Society URF** | Alexander, Baugh, Cornish, Massey, Norberg and Smail |
| **RCUK Advanced Fellowship** | Atkinson, Fielding, Gandhi, Gao, Jones, Lancaster and Swinbank |
| **Leverhulme Research Fellowship** | Abel, Alexander, Cole, VV Khoze and Smail |

**Career development:** We have a strong commitment to provide the best possible environment for our research staff to develop their careers.

- **Concordat:** The University ensures that our working polices and practices adhere to the key principles of the Research Concordat and Durham is one of only 15 UK universities awarded the European Commission HR Excellence in Research Award. All posts are advertised with clearly defined person specifications and each new research job is graded in accordance with HERA methodology. PIs are required to have recruitment and selection training. There is a clearly defined research career pathway, agreed with campus Trade Unions, which follows framework

agreement guidelines and researchers with more than 12 months service are offered redeployment opportunities by HR.

- All new staff are provided with a mentor who provides an informal, impartial and supportive relationship for the new staff member to learn his/her job and understand its context within the Department and the University. Mentoring sits alongside the more formal Annual Staff Review (ASR) process which provides an opportunity for all staff to review progress over the previous year, agree objectives for the coming year and identify personal and professional staff development needs. We have clear guidance mechanisms for academic probation and promotion in place, which are discussed in the ASR.
- New academic staff are required to study for the Postgraduate Certificate in Academic Practice (PG-CAP) which gives training and support in teaching methods, course design, teaching materials, assessment, student support and the compilation of a teaching portfolio.
- New staff are gently eased into the teaching programme during their three year probationary period with a teaching load rising from 1/3 to 2/3 and finally a full load in the third year. During this time, they are given few or no administrative tasks and have precedence in the allocation of postgraduate students. They are also encouraged to attend modules on student supervision, running research projects and a mentored programme on raising research funds.
- The Research Committee, together with the University Research Office, helps staff identify sources of external research funding and coordinates internal peer review of proposals. The Science Faculty also provides valuable additional support via peer reviews for large proposals ($> \pounds 0.5$M) and practice panels for fellowship interviews (that has lead to a 90% success rate across the faculty). Staff are actively encouraged to apply for research leave (up to one term in seven) and to apply for external research fellowships.
- RCUK and URF Fellows are treated as other junior academics and given support via PhD and 4th year project students.
- Most contract research staff contribute a small fraction of their time to teaching undergraduates and are recompensed by provision of travel funds to international research conferences. Postgraduate students and contract research staff are represented on the BoS.
- We are committed to equality and diversity issues and support this via, e.g., family-friendly flexible working hours. The Science Faculty has Athena Swan bronze status and the Department is applying for IoP Juno Practitioner status. Although appointments over the REF period are in line with the national average of 18.8% for physics departments nationally, only 12% of our research staff are female. The discrepancy is most likely due to longer term research staff on rolling contracts, research fellows with external funding and a vanishingly small number of senior women in technical positions. Our Juno Committee is investigating this issue and is tasked with ensuring that staff and students at all levels have equal opportunities.
- We have an internationally diverse staff (both fixed term and permanent). Our permanent staff originate from the UK, Belgium, Bulgaria, Denmark, France, Germany, India, Italy, Portugal, Switzerland, Mexico, New Zealand, Russia, Sri Lanka and the US.

### ii. Research students

Another vital part of our strategy is to increase significantly the number of PGR students and postdoctoral researchers, providing each with the best possible quality of experience. Our objective is to ensure facilities, financial support, training and mentorship for all our postgraduate students are amongst the best in the UK.

- PhD students are directly recruited into one of the research groups, supported primarily by studentships from the EPSRC DTA (currently totalling $\pounds 6$M for Durham University) and the STFC quota studentships (currently totalling $\pounds 4.7$M), but also through the Durham Doctoral Fellowship scheme and through various EU Training Networks. For example, The Marie Curie FP6 Early Stage Training Centre "ICCIPPP" supported five PhD students. There are currently 139 postgraduate students (95 Home, 22 EU, 22 Overseas). 22% of our PhD students are female.

- The University Director of Postgraduate Training (McComb) manages a comprehensive programme of generic skills development for postgraduate research students. Skills development is based on the Research Councils' Joint Skills Statement and incorporates components of enterprise education, delivered by the Technology Transfer Office. The quality of the programme was recognised by the Times Higher Education Award for Outstanding Support for Early Career Researchers in November 2009. These activities which are also available to PDRAs and ECRs.
- The progress of each student is closely monitored within the Department via quarterly reports and by the faculty through annual interviews and reports. Each student is assigned two supervisors. Students undertake a Training Needs Analysis, in discussion with their supervisors, during their first month of research. This is then reviewed at least annually.
- The University provides initial and continuing professional development programmes for research supervisors and formally recognises excellence in research supervision through Awards for Excellence in Doctoral Supervision, one of which was won by Hatton in 2012.
- All sections provide dedicated advanced lecture courses, notably the CPT's MSc in Particles, Strings and Cosmology which comprises 276 lectures ranging from Introductory Quantum Field Theory to Strong Interactions to String Theory. We are working together with the BSI on a new MSc in Biophysical Sciences (with Chemistry, Biological Sciences and Mathematical Sciences).
- The excellence of the work of our PhD students has been recognised externally. Dr Frank Siegert received the IoP Computational Physics Group Annual PhD Thesis prize in 2010, Dr Jeannett Gladstone received the dissertation prize from the High Energy Astrophysics Division of the American Astronomical Society in 2011, Dr Paul Siddons won the IoP Quantum Electronics and Photonics Group Thesis Prize in 2012 and Dr Adam Ingram received the 2013 RAS Michael Penston Prize for the best doctoral thesis in astronomy or astrophysics. Of the students completing their PhD since 2008, 68% remained in academic research positions with 18% taking up jobs in industry and 8% becoming teachers. Seven now hold permanent academic positions.
- The PRES results this year were excellent and well above the sector averages. It is clear that our students benefit from high quality supervision and they appreciated the access to their supervisor, high performance computers and world-class experimental equipment.
- Since 1975, the Department has organised the annual Rochester Lecture in honour and memory of Professor George Rochester FRS. A long list of distinguished lecturers includes Nobel Laureates and many Fellows of the Royal Society. Each Research Section organises an annual lecture: Grubb Parsons (Astro and CfAI), Stirling (IPPP), Gareth Roberts (CMP) and JQC (AtMol). All five Research Sections hold their own individual weekly seminar series, reflecting the strong research culture and commitment to research training within the Department. The Centre for Particle Theory holds its own colloquium series.

**d. Income, infrastructure and facilities**

**Major Research Project Funding:** The Department is funded by a wide range of sources including research councils (EPSRC, STFC, BBSRC and MRC), the EU, industry and BIS (formerly DTI and then DIUS). The total value of current grants is £46.0M and the largest sources of income are STFC (£27.7M), EPSRC (£5.7M) and the EU (£9.4M). All five Research Sections have had major successes in attracting large grants to support their work:

- CfAI is supported by an STFC consolidated grant (PI: Sharples), £2.6M (2010-15) and £1.2M (2013-15), for research and development in astronomical instrumentation for ground- and space-based telescopes, and to extend the applicability of adaptive optics correction down to visible wavelengths, and continue their successful programme of atmospheric characterisation using SLODAR. Morris leads the work on the UK programme for the European Extremely Large Telescope with grants totalling £1.9M (2010-15). Our diversification into imaging in biological systems is reflected by EPSRC grants of £0.5M (PI: Love) to film life as it develops in the heart by exploiting developments in optical microscopy, high speed imaging, and adaptive optics and £0.45M (PI: Girkin) to develop multi-object, high-throughput, spectro-microscopy.

- Since 2008, AtMol has been supported by a number of EPSRC grants including £1.1M (PI: Cornish) to study a quantum gas of ultracold polar molecules, £0.56M (PI: Cornish) to study bright matter wave solitons, £0.54M (PI: Jones) to study charge delocalisation and hopping in an ultra cold lattice, £0.61M (PI: Adams) for the dynamics of superatom quantum dots, £0.6M (PI: Hughes) for mobile atom traps based on domain walls in magnetic nanowires, £0.70M (PI: Adams) for photonic phase gates using Rydberg dark states, £0.36M (PI: Gardiner) to study relative phase and coherence in bright matter-wave solitons and £0.6M (PI: Jones) for Rydberg crystals and supersolids. The £6.4M EPSRC programme grant "MMQA: MicroKelvin Molecules in a Quantum Array" (CoI: Cornish and Carty, of which £3.6M comes to Durham) links colleagues in the JQC from Chemistry and Newcastle with Imperial College. A joint EPSRC grant of £1.0M (PI: Gardiner) was awarded earlier this year to study excitations, rotational dynamics, and rotational sensing in 2-Species Bose-Einstein condensates together with our colleagues in the JQC in Newcastle. Jones leads our involvement (0.37MEuro) in the EU Future and Emerging Technologies project "Hybrid Archicture for quantum Information using Rydbergs and Superconductors" where the idea is to couple quantum information stored in a cloud of laser-cooled atoms to a superconducting quantum device patterned on the surface.
- In its 2009 review, the ICC's International Advisory Board stated: "Durham holds a long-established position as one of the worlds leading research groups in the study of galaxy formation and large-scale structure. The formation of the ICC has substantially strengthened this position...". The Astronomy group is primarily supported by two STFC consolidated grants. The ICC rolling grant (PI: Frenk) was renewed in 2011 with a value of £2.1M (2011-15) while the observation-based rolling grant (PI: Smail) was awarded £2.7M (2011-15). These Rolling Grants were ranked 1st and 2nd out of 16 in their round. The Virgo consortium for cosmological supercomputer simulations (PI: Frenk) was awarded £1.6M (2009-13). Between 2006-10, the ICC coordinated a "Marie Curie FP6 Early Stage Training Centre" award from the EU ("ICCIPPP"), jointly with the IPPP, to support five PhD students. In 2009-2013, the ICC coordinates the "CosmoCOMP" Marie Curie FP7 Initial Training Network ), which includes nodes in the UK, the rest of Europe, China and Argentina. In 2010, the ICC were awarded a Marie Curie FP7 International Research Staff Exchange Scheme ("LACEGAL", 2011-2015) which includes most of the Cosmocomp nodes and several Latin American institutions. Frenk and Smail were awarded ERC Advanced Investigator grants in 2011 and 2012 and Norberg gained an ERC Starting grant in 2010.
- CMP is mainly supported by EPSRC grants including grants for: Protein Physics £1.1M (PI: McLeish); Materials for Xray detectors £1.2M (PIs: Brinkman and Halliday); Soft Matter Physics £1.3M (PI: Fielding); Solar Cells £1.4M (PI: Durose); Knowledge Transfer Projects £1.9M (PI: Tanner); Organic electroactive materials and lighting £2.5M (PI: Monkman) and High fields superconductors for fusion £3.2M (PI: Hampshire). Fielding won an ERC Starting grant in 2011.
- The IPPP was reviewed by an STFC international panel in 2008. The panel "considered the IPPP to be a well managed world-class institute" and a further STFC ten-year grant of £15.9M (PI: VV Khoze) was awarded. The IPPP is a partnership between the University and STFC, and as part of the renewal, the University committed three new posts, £1M for PDRAs and IPPP Associateships and committed to provide significantly increased research space in the form of the new building that is currently being designed. The well-established and widely used HEPDATA data curation facility has been funded by STFC for more than 30 years and was awarded a further tranche of funding of £0.5M (PI: VV Khoze) in 2012. Over the past five years, the IPPP has been involved in several Marie Curie FP7 Initial Training Networks "ARTEMIS", "FLAVIANET", "HEPTOOLS", "MCNet" (all 2006-2010), "LHCPhenonet" (2011-2015), "Invisibles" (2012-2016), "MCNet" (2013-17) and "HiggsTools" (2014-18) and "Neutrino and the Fundamental Laws of Nature" (2007-11), the only fundamental physics project funded by the UK-India Education and Research Initiative in that call, £150K (PI: Glover). Glover and Pascoli were awarded ERC grants in 2013.
- STFC have awarded non-PATT telescope time to consortia for legacy surveys. This income is competitively awarded but not broken down to institutions and is not reported in the REF4c data as income-in-kind. Hence the contribution has to be estimated, rather than accounted. Taking into

account the number of countries and institutions involved, we estimate our share as £1.7M.

| Non-PATT telescope time awarded by STFC | | | | |
|---|---|---|---|---|
| **Facility** | **Project** | **Period** | **PI** | **Estimated value** |
| JCMT | SCUBA-2 Cosmology Legacy Survey | 1/8/2011-31/1/2014 | Smail | £0.937M |
| UKIRT | HiZELS campaign programme U/CMP/3 | 1/8/2008-31/1/2013 | Smail | £0.629M |
| JCMT | SCUBA-2 Lensing Survey | 1/2/2012-31/1/2013 | Smail | £0.153M |

**Physical Infrastructure and Facilities:** The Department currently occupies over 5800m$^2$ of space in Durham including the Ogden Centre for Fundamental Physics. There are communal condensed matter experimental facilities including a Quantum Design Physical Properties Measurement System, QD SQUID, vibrating sample magnetometers, UHV scanning probe microscope, X-ray diffraction equipment, femtosecond time resolved laser spectroscopy systems and several vertical high field magnets including a 15T split-pair horizontal magnet.

- The Ogden Centre, supported by PPARC, HEFCE, JIF, the University and the Ogden Trust, was opened in 2002 and houses the ICC and the IPPP. The IPPP grid farm, funded by £120k from the university in 2008 commenced operation in January 2009, was upgraded in June 2011 (£85k), and now comprises 955 cores, 1.9 Tb RAM and 30 Tb shared disk that can be accessed via the Grid storage mechanisms, and is located in a dedicated machine room in the Ogden Centre.
- Another key University-wide facility for capturing and exploiting impact is NETPark (North East Technology science park), in Sedgefield, County Durham. Durham Physics plays a major leadership role in NETPark, with its CfAI group and Kromek spin-out company as anchor tenants (see Case Studies Precision Optics and Kromek). CfAI runs approximately half its activities at the NETPark Research Institute which is a 600m$^2$ laboratory and office complex specifically designed for building large complex instruments for astronomical observatories, e.g. components of ESO's KMOS spectrograph (PI: Sharples).
- The Department hosts the GJ Russell Microscopy Facility which is a joint facility shared between five departments (Physics, Chemistry, Earth Sciences, Engineering and Biology) funded by £1.8M from SRIF3. The facility boasts a number of state of the art scanning and tunneling electron microscopes for extracting structural and chemical information at the nanometre and atomic scale. The focused ion-beam microscope enables novel structures, such as MEMS and NEMS devices, to be engineered. New academic (Mendis) and technical appointments support this facility.

**Infrastructure Investment:** We are in the process of developing a new £10M Physics Research Facility of roughly 2500m$^2$ to provide increased research space for IPPP and Astro. The new facility will complement the existing Ogden Centre for Fundamental Physics and will be located adjacent to the current Physics building. A major donor has committed several million pounds towards this project. In addition, the world famous architect Daniel Libeskind has been commissioned to provide the final design for the building.

- In 2009 the University funded the refurbishment of the Arthur Holmes HPC machine room to add watercooling via free-aircooling chillers (£900K) for the installation of COSMA-4 and COSMA-5.
- In 2010 the ICC procured the COSMA-4 HPC cluster which was upgraded twice (July 2011 and November 2011) and now comprises of approximately 3000 Intel Westmere cores with a total of 15 TByte of RAM and a 4xQDR infiniband for interprocess communication. The system includes a 1.1 PByte of GPFS storage system served over the cluster's infiniband and RDMA. COSMA-4 is part of the DiRAC-1 project and was funded by £1.29M from STFC and £900K from Durham University. COSMA-4 serves the ICC and its coworkers from the Virgo Consortium.
- In October 2012, COSMA was massively upgraded with COSMA-5 (the DiRAC-2 Data Centric System) which provided an additional 6720 Intel Sandy Bridge cores and 54 TByte of RAM with an FDR10 interconnect. Storage is provided by a 2 PByte GPFS filesystem served to the cluster via infiniband. The project was funded with £3.3M from STFC as part of the DiRAC-2 project plus

an additional £400k for cooling and power infrastructure upgrades to house the system. COSMA-5 is a national facility serving the astrophysics community for large scale grand challenge projects.

- In addition to interdisciplinary equipment located in other Departments, and the investment in the GJ Russell Microscopy Facility, the University has heavily invested in infrastructure in the Physics Department since 2008: including a frequency comb for precision studies in atomic, molecular and optical physics (£400K); X-ray diffraction equipment (£575K); for X-ray tomography (£593K); thin film spintronic fabrication (£200K); biophotonics and optical microscopy (£200K); £120K for a refresh of the IPPP Grid computing system; £100K to join the Pan-STARRS sky survey.

**Centrally provided infrastructure:** In addition, a number of Professional Support Services (PSS), play key roles in enabling and promoting our research effort. For example,

- The Development and Alumni Relations Office (DARO) has played a key role in identifying and approaching philanthropists and philanthropic organisations that have generated an additional £420K of research support since 2008. Maintaining our relationship with existing donors and fundraising events to develop new relationships is a key part of supporting our research effort.
- The International Office facilitates strategic institutional level partnerships with key universities world-wide, e.g., Harvard University, Peking, Kyoto, University of Sao Paolo as well as the Matariki Network of Universities (MNU). This benefits research student exchanges, development opportunities for early career researchers, the facilitation of longer term research collaboration as well as providing financial support for workshops such as the Durham-Dartmouth extragalactic workshop in Dartmouth July-August 2012 (organised by Alexander).
- In addition to effective research grant support, including research systems in support of service delivery, and impact, the Research Office plays a key support role in the preparation of multi-disciplinary bids to RCUK and EU proposals, particularly for ERC grants and EU Networks.
- Computing and Information Services (CIS) provides a research oriented IT estate with a secure network environment for all areas of the University and local research networks in some Departments. Since 2011, there has been major investment including an increase in the bandwidth of its connection to the JANET to 4Gb in 2011 and which is expected to reach 10Gb by 2014.
- An £11.5M extension to the Bill Bryson library saw a 42% increase in its size and there has been a 44.4% increase in resource spend on Physics since 2008 with £229K spent on books, journals and other serial publications in 2012/13. Our open access institutional repositories, Durham Research Online (DRO) and Durham E-Theses, maximise the dissemination of research outputs outside of the academic community.

**e. Collaboration and contribution to the discipline or research base**

In this section we give some highlights of our contributions to the wider research base.

**Research Collaborations**

- **Strategic Partnerships:** The Department and University have developed a strong strategic partnership with Proctor & Gamble through the Biophysical Sciences Institute (led by new appointments Girkin, and Bromley, Fielding, McLeish) which led to the award of a £5.3M grant from the UK Secretary of State for Business, Innovation and Skills' Regional Growth Fund (RGF) scheme. Durham was P&Gs Global Business Development University Partner of the Year for 2012. Through the URI and Durham Business & Innovation Services (DBIS), we are hoping to develop similar relationships with other blue chip companies.
- **Collaboration with other Durham Departments:** Several staff have joint appointments with other Departments, e.g., Abel, Gregory (Mathematical Sciences), Carty, Hutson, McLeish, Staykova (Chemistry) which naturally leads to joint publications. University Centres are more formal recognition of the ongoing research links between Departments, e.g., the Centre for Particle Theory (Physics, Mathematical Sciences), the Centre for Soft Matter (Chemistry, Physics, Mathematical Sciences, Engineering) while the Durham X-ray Centre (Chemistry, Physics, Earth Sciences, Biology and Biomedical Sciences, Engineering, Health, Archaeology and Geography) is the largest centre in the University with 41 permanent staff. The Centres typically give a fo-

cal point for postgraduate training (e.g., CPT), regular cross-campus seminars (all) and hosting high profile external visitors, e.g., Prof. David Nelson of Harvard (CSM). CSM also participated in sandpit sessions with Michelin, Unilever and P&G which led to funded research projects including the EPSRC CDT in Soft Matter and Functional Interfaces.

- **Interdisciplinary Research:** The University Research Institutes such as the BSI, DEI, WRI, iARC and IAS, aim to develop and deliver research projects that look to solve major challenges that are inherently multidisciplinary and act as a focus for interdisciplinary research. For example, the BSI was created to help solve large research questions in the life sciences by developing and applying physical science expertise alongside life science researchers and clinicians. It acts as a catalyst in the development of larger projects and the associated project teams either by inviting world leading scientists for focused short meetings on a specific subject, coordinating applications for funding or acting as a gateway with industry. For example, the very successful Durham/P&G link started with a small meeting organised within Durham in which a range of scientists presented areas that were known to be of interest to P&G covering all branches of science. A similar small scale meeting led to the development of international collaborations with the Washington State University in the study of the development of the eye (Leverhulme funded project with Biology and Biomedical Sciences, Physics and Engineering).
- **Regional Links:** The Joint Quantum Centre (JQC) links staff working on various aspects of quantum physics in the Physics and Chemistry Departments in Durham and Applied Maths and Engineering at Newcastle, with common seminars and shared grants (e.g. $\pounds 1$M EPSRC grant) leading to common publications. Durham is part of the N8 Research Partnership that links the eight most research intensive universities in the North of England. In addition to widening access to research infrastructure in the North, it offers more opportunities to develop links with the private sector and led, for example, to funding to engage with Spartan Nano to actively pursue research on a novel approach to enhancing surface based antimicrobial activity (PI: Atkinson).
- **Visiting Professors:** Our cohort of more than 20 Visiting Professors ensures strong links with a range of key collaborators, e.g., Simon White (MPA Garching), Thomas Gehrmann (University of Zürich), and key research partners, e.g., Michael Duncan (European Director of Innovation and Academic Relations at Procter & Gamble), Rolf Heuer (Director General, CERN).
- **International Collaborations:** We are involved in, and frequently provide leadership of, a number of astronomical instruments such as VST ATLAS, Pan-STARRS, EUCLID, KMOS, Cherenkov Telescope Array or the European Extremely Large Telescope. For example, KMOS (PI: Sharples) is an 18MEuro multi-object infrared spectrograph being built by a consortium of UK and German institutes and will be the first UK-led common user instrument for the ESO VLT. Durham will lead the 250 night GTO (Guaranteed Time Observation) programme which has an equivalent value of 12.5MEuro. Another example is the prestigious ESO public survey VST ATLAS (PI: Shanks) which aims to make an imaging survey of much of the Southern sky to similar depths to SDSS in the North. The Virgo consortium (CoPI: Frenk) is a leading international collaboration from the UK, Germany and the Netherlands working on numerical simulations of the growth of structure.
- **EU networks:** Consistent with our strategies to diversify our research income and build international partnerships, most of our Research Sections have been involved in EU funded research and/or training networks; for example, Astro ("ICCIPPP" 2006-10, "Cosmocomp" 2009-2013, "LACEGAL" 2011-15), AtMol ("Coherence" 2012-16), CMP ("SoftComp" 2005-9, "DYNACOP" 2009-13), IPPP ("ARTEMIS", "FLAVIANET", "HEPTOOLS", "MCNet" all 2006-2010, "LHCPhenonet" 2011-2015, "Invisibles" 2012-2016, "MCNet" 2013-17, "HiggsTools" 2014-18). Each of these networks focuses on a particular research theme and typically links ten or more institutions and provides funds for about 20 young researchers. For example, the Marie Curie FP7 Initial Training Network "CosmoComp" (coordinator Baugh) links researchers in Nottingham, Sussex, MPA Garching, Leiden, Trieste, Saclay, Barcelona, CONICET(Buenos Aires, Cordoba, Argentina) and Shanghai while "Invisibles" (deputy coordinator Pascoli) links Madrid, Durham, Aarhus, CNRS, MPI Heidelberg, Gottingen, INFN, Barcelona, Valencia, Zurich and Southampton. "Coherence" (2012-16) focuses on the special properties of Rydberg atoms at very low temperatures that will

impact on a broad range of topics including: condensed matter physics, polymer and biophysics, molecular physics, quantum optics and quantum information, surface physics, plasma physics, and laser technology while "MCNet" leads the development of event generators for the simulation of LHC events.

**Leadership and community contributions**

- **Selected National/International Committes and Panels: Royal Society:** 2 including Council (Frenk); **IoP:** 12 including Council (McLeish (Vice-president, Science) and Love); Groups Committee (Love); Accreditation Committee (Morris, Vice-Chair); Astroparticle Group (Chadwick, Chair, 2008); Optical Group (Love, Chair 2007-10); Magnetism Group (Hindmarch, Treasurer); Division of Atomic, Molecular and Optical Physics (Hughes, Secretary 2011-12). **STFC:** 30 including Science Board (non-core members VV Khoze, Morris), PPRP (Chadwick, Deputy Chair); AGP (Smail, Deputy Chair). **EPSRC:** 18 including HPC Panel (Clark, Chair, 2009); Peer Review Panel (Adams, Chair, 2009 and 2011); NPL Fellowship Panel (Girkin, Chair, 2010-2011); Early Career Fellowship Panel (Girkin, Chair, 2011). **Other:** 52 including Wakeham Review of "The health of Physics in the UK" (Frenk); Chair of ERC Advanced and Starting grant panels (Ward).
- **Editorial Boards:** 10 including Superconductivity Science and Technology (Hampshire, Editor in Chief); Journal of Physics G (Martin, Deputy Editor); Journal of Physics B (Adams, International Advisory Board).

**Conferences and workshops**

- **Invited Keynote/Plenary Lectures:** All members of academic staff are encouraged to present their work at international conferences and the Department makes funds available to help staff attend when necessary. Over the REF period our staff have given more than 450 invited keynote and plenary lectures at major international conferences world-wide as well as contributing to a large number of national and regional meetings.
- **Conference Organisation:** Our staff have served on the advisory or organising committees of more than 200 national or international conferences. We also make use of the superb conference facilities available in Durham to host conferences and national training schools. Stimulating interactions between experimental and theoretical particle physicists is part of the IPPP's mission and we organised and/or sponsored 100 topical workshops and schools either in Durham or elsewhere in the UK during the REF period. Major conferences held at Durham in the period include: Galaxy Formation (2011), IoP Photon 12 (2012), Ripples in the Cosmos (2013), 11th International Symposium on Radiative Corrections (Applications of Quantum Field Theory to Phenomenology) (2013). We have also organised/co-organised international PhD+ level training schools in particle physics every year during the REF period.
- **Royal Society Summer Exhibition:** We contributed exhibits in 2009, 2010, 2012 and 2013.

**Recognition**

- **Prizes and Awards: IoP:** High Energy Particle Physics Group prize (Richardson, 2009); Hoyle Medal and Prize (Frenk, 2010); Polymer Physics Group Founders' Prize (McLeish, 2011); Division of Atomic, Molecular, Optical and Plasma Physics Bates prize (Jones, 2011); Occhialini Medal and Prize (Pascoli, 2013). **RAS:** Group Achievement Award (2008 and 2012); George Darwin Prize (Frenk, 2010); Michael Penston Best PhD Thesis Prize (Li, 2010); Fowler Award (Swinbank, 2013); Winton Capital Award (Li, 2013). **Other:** Bronze Medal from the Centre National de la Recherche Scientifique (Boehm, 2008); Philip Leverhulme Prize (Alexander (2009), Massey (2011) and Swinbank (2013)); Gold Medal of the British Society of Rheology (McLeish, 2009); Arthur B. Metzner Early Career Award of the Society of Rheology (Fielding, 2010); Bingham Medal of the Society of Rheology (McLeish, 2010); Mitchell Prize of the International Society for Bayesian Analysis (Bower, 2011); Gruber Prize for Cosmology (Frenk, 2011); The Queen's Award For Enterprise Promotion (Tanner, 2012); Alexander von Humboldt Research Award (Frenk, 2013); Biermann Lectures (Frenk, 2013); Royal Society Wolfson Merit Awards (Frenk (2007), Glover (2008), VV Khoze (2012), Smail (2013)).
- **Fellows of Learned Societies: Royal Society:** 4; **IoP:** 16; **RAS:** 12.