Institution: Plymouth University

Unit of Assessment: Mathematical Sciences B10

a. Overview

We are an active and committed group of researchers, working in a stimulating and well-supported research environment. Our strength is research excellence in a wide and diverse range of scientific and applied disciplines. The UoA consists of sixteen scientists from the **Mathematical Sciences Research Centre** within the School of Computing & Mathematics, in the Faculty of Science and Technology. A broad range of research areas is covered including:

Particle Physics

For many years the Plymouth Particle Theory Group has undertaken internationally leading research into quantum field theory and its applications. Recent appointments of young researchers have reinforced the group, which now consists of seven permanent staff and focuses on numerical methods employing high performance computing (HPC).

The research of the group is centred on the Standard Model of particle physics. Its focal points are theoretical studies of the properties of matter under extreme conditions, physics beyond the Standard Model, and quantum field theories in external fields. The group uses HPC for first principle simulations of these theories. In 2009, we were invited to join the collaboration network *UKQCD*, which includes high-profile research groups at UK universities, including Cambridge, Edinburgh, Glasgow, Liverpool, Oxford, Southampton, and Swansea, as well as our Plymouth group.

Statistics

The Plymouth University Statistics Group is an application-focused, active and committed cluster of young researchers, whose remit is broad and whose work is underpinned by the methodological theme of computationally intensive Bayesian modelling.

Group members are working on a range of methodological, applied, and consultancy projects. The interdisciplinary nature of our work, as well as our international links and connections with government departments, provides us with plentiful, real-life data, all of which we find motivating. Such connections mean that we are able to maintain the relevance and applicability of our work for research users, whilst ensuring that it has international impact. The group has close working relations with epidemiological statisticians led by Wright, who work on foetal abnormality screening and clinical trials with colleagues in the Medical School (work submitted to UoA1).

The Plymouth-based Royal Statistical Society South West Group holds the majority of its meetings at Plymouth University. We are active members of the statistics community, performing refereeing and associated editorial duties for international journals and grant awarding bodies. Since 2000, group members have also served as Treasurer to the Committee of Professors of Statistics, and the Council and General Applications Section Committee of the Royal Statistics Society.

Fluid Dynamics and Engineering Mathematics

Staff in the Industrial and Engineering Mathematics research group share a common interest in the application of analytical and numerical mathematical methods to problems that arise in industrial or engineering contexts. Current areas of interest include applied fluid dynamics and materials science.

Pure Mathematics

The diverse range of research interests of the Pure Mathematics Group includes graph theory,

dynamical systems, history of geometry, and twistor theory. A member of this group has served as General Secretary and Trustee of the London Mathematical Society (LMS). The LMS helps to inform UK research and education policy in mathematics, especially in exercises such as the REF and IRM. We also take an active part in European research policy, supporting the European Mathematical Society in its efforts to co-ordinate the work of the mathematical community in Europe.

b. Research strategy

Research is an integral part of the overall mission of the Mathematical Sciences Group at Plymouth University. Our research strategy aims at **selectivity in enhancing research excellence** and **supporting a sustainable research culture** to nurture a diverse range of topics. The strategy aims to develop excellence in computer-assisted research, ranging from particle physics through engineering mathematics to the development of computational statistics methodology applied to a range of real problems of social importance. Our selective focus centres on particle physics and statistics, with supporting work in pure mathematics and in fluid dynamics and engineering mathematics.

Our strategic vision foresees two key tasks:

(i) To continue to produce **world-class research** results that are, in part, assisted by HPC. At the same time, we will stay at the forefront of HPC technologies by exploring new energy efficient HPC hardware, fully supported by the University's Green Agenda. We will extend our existing links to industrial companies such as IBM and government bodies such as the NHS, and we will forge new strategic partnerships and collaborations, detailed below.

(ii) To maintain and consolidate research excellence and the **vibrant research environment** through the building of appropriate structures of research governance. The formation of an HPC Centre (HPCC), led by *Langfeld*, is an example. This bundles our HPC expertise, offers synergy effects by sharing the resource with other research groups beyond faculty boundaries, and is a collaboration platform for our diverse research projects as well as for external engagement.

A first step in towards expansion in particle physics had been the appointment of an expert in high performance computing (HPC). Since 2008 we have further developed this area through further appointments of two internationally recognised experts in particle physics simulations. This has significantly broadened our excellence in this field and has enhanced our opportunities for achieving impact through the forging of industrial links with organisations such as IBM. Since 2008, our thriving research culture has been further strengthened by the appointment of two promising young researchers in statistics. With these appointments, the collaborative links between the research groups within the Mathematical Sciences Group have been significantly improved.

A further step forward in the delivery of our strategy has been the recent establishment of a **Mathematical Sciences Research Centre** to act as a strategic focus for our work and as a basis for collaboration with colleagues in other parts of the university. This Centre was established under the University Research and Innovation Strategy, which signals areas of selective investment and strategic development for the university. The Mathematical Sciences Research Centre provides the essential framework for governance and coordination. It serves as a unique point of access for external engagement and for the monitoring of engagement and impact, it provides support for grant applications, and it provides assistance with recruitment. The Centre reports annually to the Faculty Research Committee and its work is monitored by the University Research and Innovation Committee.

In addition to the formation of the HPCC, external partners have been involved in the formation of a Financial Risk Task Force and an Industrial Mathematics Working Group as governance mechanisms to benefit from the transferable expertise in particle physics, statistics, and engineering mathematics.

These developments have allowed us to work more closely with colleagues in the Medical School and Health faculty, where Wright's group of epidemiological statisticians (submitted to UoA1) have long-established relations such as a project on intelligent biomedical data analysis for brain diseases and cancer led by Prof. E. Ifeachor (UoA 13) in the Electrical Engineering section of our School. These collaborative links are the corner stone of our future strategy to enhance and sustain a vibrant research culture. Our aim is to empower our collaborative groups to create sufficient momentum to attract funding targeted at interdisciplinary collaborations, and to extend this collaborative work to include third party industrial partners.

Our strategy has been highly successful, leading to high-profile research achievements, which have been published in top-ranked research journals, and with staff also having been invited to present their results at major international conferences. Computationally intensive simulations carried out by the Statistics Group have led to new funding opportunities in research fields ranging from medical statistics to environmental monitoring. Our plans involve further expansion of research students and postdoctoral research assistants. In furtherance of this plan, we are actively responding to funding calls by the Research Councils, and we are fostering stronger links with industrial groups working in research & development.

c. People, including:

i. Staffing strategy and staff development

There has been significant investment in staffing since 2008, new appointments being made to further our research strategy. The School of Computing & Mathematics actively supports our research strategy through funding for newly created staff positions that will attract applicants with a strong research focus. This support is integral to the School's Strategic Planning for the next four years and in relation to the University 2020 Strategy.

Dr Antonio **Rago** was appointed from the University of Wuppertal, Germany, in 2010, and, in 2012 we attracted Dr Agostino **Patella** from a prestigious fellowship at CERN, Switzerland, to further strengthen the particle physics group. Dr Luciana **Dalla Valle** from the University of Milan, Italy, and Dr Irene **Kaimi** from the University of Cyprus, Nicosia, have been appointed to broaden the research remit of the Statistics Group. These appointments have enhanced our commitment to international expertise and diversity**,** with research-active staff now including Argentinian, Cypriot, German and Italian nationals. In addition to these new appointments, the University has recognised the strength of research in Mathematical Sciences by promoting Dr Kurt **Langfeld** to Professor in Theoretical Physics, Dr Stephen **Huggett** to Professor in Pure Mathematics, Dr Martin **Lavelle** to a readership, and Dr Tom **Heinzl** and Dr Paul **Hewson** to senior lectureships.

New appointments have been made with a view to both enhancing research capacity and ensuring leadership succession through having a balanced structure of staff at various career stages. The recent appointment of the outstanding Italian scientist **Rago** brings to the group an internationally recognised expert in particle physics and HPC. He strengthens the national and international network of the Plymouth Particle Physics Group with his links to the UKQCD collaboration, developing lattice field theory calculations of elementary particle interactions, and the StrongBSM network, the world leaders in models of dynamical electroweak symmetry. As a developer of the Linux operating system DEBIAN, and as a consultant for IBM, **Dr Rago** possesses excellent HPC skills and has consequently been invited to become an HPC OS administrator.

Patella is an mid-career scientist (PhD 2008) who already has a track record of high profile research publications. He holds a prestigious CERN fellowship and is an expert in particle physics and computer simulations. He will enhance our expertise in the strategically important field of particle physics. **Valle**, **Kaimi**, and **Palacios** have been recruited as early career scientists to enhance research succession within the group. **Valle** has strengthened the Statistics Group with her expertise in computationally intensive approaches to financial risk analysis, customer satisfaction surveys and multilevel modelling with applications to internationalization, one of the University's key strategic directions. **Kaimi** has brought considerable expertise in spatio-temporal

statistics with applications for biomedicine, another of the University's key strategic directions, and environmental modelling, one of the research targets identified in RAE 2008 for nationwide attention, and attracting particular government support. **Palacios** joined us in February 2013 to strengthen our work in Bayesian inference and stochastic modelling.

Appointments and promotions are made in accordance with the University's commitment to the recognition of equality and diversity. The outcomes of these processes are monitored at School and now Research Centre level. Recent appointments have significantly improved the gender and age balance of the group. Women now make up 21% of our research active staff. A recent gender survey of UK Mathematics Departments by the London Mathematical Society has revealed that the sector average for women working as professors in Mathematics is only around 6%.

We run an active seminar series that has brought well-known scientists to Plymouth from Canada, Germany, Ireland, Spain, Sweden, Switzerland (CERN), and the United States of America, as well as from other parts of the UK. Some of our statistics seminars form part of the programme of the Royal Statistical Society South West. The School also supports research collaborations by subsidising the international exchange of researchers and attendance at conferences and workshops.

In line with the Concordat to Support the Career Development of Researchers, under which Plymouth University was awarded the HR Excellence in Research Award, we have put in place a Personal Development Framework and a dedicated mentoring system that address all stages of career development and all aspects of academic practice.. Early career researchers are assigned to an experienced mentor who is able to advise them on all aspects of their work at Plymouth. All newly appointed members of staff have the opportunity to undertake training to achieve the Postgraduate Certificate in Academic Practice (PGCAP) and to seek accreditation as a Registered Associate or Fellow of the Higher Educations Academy (HEA). New members of our Centre are provided with work relief to ensure that they are able to complete the programme successfully and that they can develop their own research. The Graduate School provides training in Research supervision and PhD examination**,** which is compulsory for all new staff and is central to our work with postgraduate students detailed below.

ii. Research students

Research students in Mathematical Sciences are part of the newly developed Doctoral Training Centre (DTC) for Computing & Mathematics led by **Langfeld**. The DTC management board is part of the School's Research Committee, which is also chaired by a member of the Centre. This ensures that the students' research is at the heart of the wider School research strategy. School support is apparent in its establishment of an annual **PhD studentship** for allocation by the Mathematical Sciences Research Centre.

Research students undertake independent research in a flexible and stimulating environment. The current cohort in the two areas comprises 123 postgraduate students who all fall under the remit of this DTC and benefit from its cross-disciplinary environment. The aims of the DTC have been formulated to conform with the recommendations of the European University Association (EUA), and embrace the 'Practice of Research'. Students follow their individual pathways through the DTC supporting structure. This support includes the regular monitoring of student achievement, and offers a variety of modules that provide training in specialised research topics. The work of the DTC and supervisors is overseen by the University Graduate School, which also provides generic training and support. In line with the suggestions of the Wilson Review of Business-University Collaboration (2012, on the authority of the Department of Business, Innovation and Skills), our students are also encouraged to attend national courses for generic skills development and entrepreneurship.

Our students' satisfaction about the supervision they receive, the provision of infrastructure to support their projects, and the environment for PGR studies are monitored on a regular basis. We use a newly developed electronic PGR logbook, which is accessible by a standard web browser,

and which lists all deadlines from initial registration to the viva voce examination on one entrance page. This logbook enables students and staff to schedule meetings, and provides a facility to upload documentation for the auditing process.

Our research students are very much embedded in the thriving research culture of the Mathematical Science Research Centre. A staff open-door policy encourages research students to interact with all appropriate members of staff, and not just their Director of Studies. Students participate in our research seminars and present their work at Centre staff seminars. Our final year students are encouraged to present their work at national and international conferences, with School, Centre, and DTC funds available for this purpose.

d. Income, infrastructure and facilities

Our international reputation for world-class research using high performance computing resources has triggered the formation of the HPCC. Due to the activities of our particle physics group, Plymouth University (PU) has been invited to join the collaboration network UKQCD, which includes high-profile research groups from nine UK universities including Cambridge, Oxford, and Edinburgh. In 2010, PU was invited to join the UKQCD consortium, and, in 2010, the Science and Technology Facilities Council (STFC) awarded UKQCD funds within the embedded *Distributed Research utilising Advanced Computing* (DiRAC) framework. This framework provides UK particle physicists and astronomers with upgraded HPC technology to address some of the most challenging scientific problems. Approximately 56% of HPCC hardware has been funded via this route. Besides the Plymouth University facility, the grant also allows researchers of the Mathematical Science Research Centre to access the IBM supercomputers Blue-Gene Q/P at the University of Edinburgh and Swansea University.

The remaining 44% of our HPCC equipment has been funded by grants awarded to the Peninsula Research Institute for Marine Renewable Energy (PRIMaRE). Both research groups benefit significantly from the synergy effects arising out of centrally-provided technical support and the bundled expert advice from senior and HPC-experienced scientists. The Centre is hosted by the Faculty of Science and Technology and is open to researchers across Plymouth University, which supports these activities by covering the substantial running and maintenance costs and providing technical staff. The HPCC now works with the Research & Innovation Division of the University, to offer HPC support and consultancy to third parties.

In line with the University's Green Agenda, the School of Computing & Mathematics recently invested in new GPU-based technology for the HPCC, supplementing the GPU facility that is already operational in our Statistics Group. To sustain our HPC facility and HPC-driven research activities, we received in 2013 a total of 130M core hours of supercomputer time (£778k notional value allocated to PU), which was a direct allocation by the Department for Business, Innovation & Skills (*BIS*) via the DIRAC II framework.

Our Statistics Group has a sustained track record of funded research: our collaboration network has attracted £548k for research in the REF period. This has helped us to build a reputation for applications in the field of small area estimation, including Bayesian models for sample surveys, small area predictions, and disclosure control. Following earlier success in other aspects of this work, we have recently been successful in obtaining grants for the production of small area estimates of morbidity, with a view to informing resource allocation in the health service. This work is cross-faculty and includes external collaborators; recently-awarded grant recipients also include staff at Exeter, Southampton and St. Andrews. Recognition of our work in road safety research, as well as our teaching expertise, has yielded two multidisciplinary grants worth £235k in total, awarded through the Knowledge Transfer Partnerships (KTP) scheme.

e. Collaboration and contribution to the discipline or research base

As evidenced by our publication record, the group has been embedded in an international network

of high profile researchers and has published with scientists from countries including Australia, Canada, Germany, Italy, Sweden and the USA during the REF period.
School and Faculty funds support our research activities by allowing us to invite world-leading researchers to work with us. **Professor (Emeritus) Ferdinando Gliozzi** (INFN, University of Torino, Italy) is one of the world experts in numerical Quantum Field Theory, and has been part of a long-standing research collaboration with **Dr Antonio Rago**. **Professor Claudia Czado** (Technical University of Munich, Germany) is a world expert in Statistics, and will continue her fruitful collaboration with **Dr Luciana Dalla Valle**, which started in 2008. Both Professors will visit us for 3 months at the end of 2013 and in early 2014, respectively.

A collaboration between the Particle Physics Group and the Engineering Mathematics Group is currently forging a strategic alliance with a group at the University of Aalen, Germany, headed by Prof. Feuchter, and with the MAHLE group with headquarters in Stuttgart, Germany. The initial collaboration is based on a joint, industry-funded PhD project in the field of Micro-filter technologies. Our vision here is to grow these links into an industrial collaboration and, in academia, into a research node, facilitating an active exchange of research students.

The Particle Physics Group actively participates as a member of UKQCD, which is a consortium of high-profile particle physics groups at eight UK universities: Cambridge, Edinburgh, Glasgow, Liverpool, Oxford, Southampton, and Swansea, as well as Plymouth. The mission of UKQCD is to form strategic alliances for large-scale grant applications, which are targeted at supercomputer resources, and to facilitate collaborations between high-profile theory groups using computer simulations in particle physics. Members of the Fluid Dynamics and Engineering Mathematics Group were awarded a prestigious EPSRC grant to develop a 'Virtual Wave Structure Interaction (WSI) Simulation Environment'. This grant was awarded to our Industrial Engineering Mathematics group, together with the Centre for Mathematical Modelling and Flow Analysis (Manchester Metropolitan University), the Marine Research Centre (Plymouth University), and the Software Engineering Group (STFC, Rutherford Appleton Laboratory, Didcot, UK). This grant greatly strengthens our collaborative links with these groups.

We inform decision making at a high national level. **Prof. Stephen Huggett** was an Officer and Trustee of the *London Mathematical Society* (LMS) from 2001 to 2011, helping to inform UK research and education policy in mathematics, especially for exercises such as the REF and IRM. Our Statistical Research group informs the decision making of important statistical societies. Since January 2012, **Dr Julian Stander** has been an elected member of the Royal Statistical Society (RSS) Council. Since 2004, he has served as Chair of the South-West Local Group of the RSS, and as Treasurer of the Committee of Professors of Statistics since 2000. **Stander** serves as the Secretary of the General Applications section for the RSS.

We also contribute to policy making at an international level, where **Huggett** is the Secretary of the European Mathematical Society, coordinating the work of the mathematical community in Europe and influencing European research policy. He also chaired the committee responsible for formulating UK policy input for the *International Mathematical Union*, notably at its meeting in India in August 2010.We contribute to the dissemination of research by the Board of the *European Mathematical Society*. **Dr Tom Heinzl** serves as the particle physics coordinator of Extreme Light Infrastructure (ELI), a European Project involving nearly 40 research and academic institutions from 13 EU-member Countries. He also contributed to the white papers for the Bucharest-Magurele laser facility, which is part of ELI, and to the project of the Rutherford Appleton Laboratories in Oxford for the upgrade of the Vulcan laser to 10 Petawatt (PW). Members of the FDEM Group have served as members of the steering group for the Smoothed Particle Hydrodynamics European Research Interest Community (SPHERIC) and of the scientific committee for the last three annual international workshops on *Smoothed Particle Hydrodynamics* (2010-2012).

Staff members regularly act as referees for the top international research journals. Members of the Particle Physics Group regularly serve as referees for a variety of high profile research journals, including high impact factor journals such as *Physical Review D* and *Physical Review Letters*. Our

efforts are well acknowledged and the American Physical Society awarded 'Referee of the Year 2010' to Dr Tom Heinzl. A member of the Statistics Group acts as editor of the journal *Teaching Statistics*. Members of the Fluid Dynamics and Engineering Mathematics Group serve on a regular basis as referees for high profile journals such as *Chemical Engineering Research and Design* or the *International Journal for Numerical Methods in Fluids*.

We participate in the research evaluation and decision-making of research councils on UK and international grant allocations. **Prof. Kurt Langfeld** served as an EPSRC panel member for the final evaluation of proposal submissions responding to the DEISA call (Distributed European infrastructure for Supercomputing Applications). He also acted as a consultant evaluating grant proposals for the Swiss National Supercomputing Centre (CSCS) in 2011 and 2012. He is also a referee for the Austrian Research Council (FWF).

Unusually for a mathematics group, the work of our centre has attracted mass media attention. In early 2013, **Prof. David McMullan** was able to break the code of hidden messages in letters from British wartime prisoners in World War II German prison camps. This success featured in BBC One prime-time television news, broadcast nationwide, and has been picked up by the international press (e.g., CBS, France2, etc.).

Our work contributes to the academic knowledge base in other disciplines through publication and research activity. Members of the Particle Physics Group have published more than 19 papers in peer-reviewed journals with high impact factors. The total number of citations attributed to its members for the REF period is approximately 1080. With a successful pre-proposal, members of the HPC group were invited to submit a full proposal for a prestigious Research Project grant from the Leverhulme Trust. Members of the Statistics Group are regularly invited to high-profile conferences, such as the International Conference on Computational and Financial Econometrics (CFE'11).

As outlined in the document REF3a – Pathways to Impact, the computational fluid dynamics group is of strategic importance for forging industrial and third party links, thereby generating impact. Consequently, this group is a focal point for strategic expansions: two further permanent staff members will be appointed in this research area by the end of 2013. An EPSRC funded postdoctoral research fellow will contribute to the above-mentioned WSI project and will work with us for three years starting in October 2013.