Institution: University College London

Unit of Assessment: 10

a. Overview

Research in Mathematical Sciences at UCL is shaped by a shared vision of excellence, characterized by depth, rigour and application. This vision informs areas of traditional research strength at UCL, in analysis, fluid mechanics and statistical methodology for example. It has also driven our recruitment strategy and new research directions, for example in geometry, applied and numerical analysis, computational statistics and networks. While the focus of expertise is in the two departments of Mathematics and Statistical Science, our collaborations reach out across the full range of research intensive disciplines at UCL.

b. Research strategy

Achievement of strategic aims

Mathematical Sciences research is thriving at UCL and has, post RAE2008, shown a remarkable increase in activity in many research areas and in various performance indicators. This is a direct result of strong institutional support and priority investment in Mathematical Sciences as recommended by an external review of research of both departments immediately following RAE2008. Additionally, we have deliberately sought to raise our UK and international profiles by engaging proactively and enthusiastically with the wider mathematical community through, for example, hosting and organizing meetings, and immersing ourselves in the running and promotion of UK mathematics and statistics. Research highlights that occurred during the REF period as a direct result of this strategy are listed below.

1. Since RAE2008 there has been a steady and planned growth in the number of Mathematical Sciences researchers at UCL: the number of Category A staff submitted to the REF in comparison to RAE2008 (units 20, 21 and 22, encompassing pure and applied mathematics and statistics and operational research) has increased by almost 50% from 45.25 FTE to 62.95 FTE. The size of the statistics group has nearly doubled in this period: from 13.1 FTE to 25.3. Many of these new staff are research leaders (e.g. **Burman**, **Girolami**, **Singer**, **Wolfe**) and their presence has been vital in sustaining and creating new research areas and in fostering Early Career Researchers (ECRs) of which there are 9 FTE in this submission.

2. Following institutional support primarily through the establishment of a 'Teaching Assistant' scheme, but additionally using innovative UCL scholarships and fee-waivers alongside traditional funding sources (e.g. EPSRC DTG), the number of PhD students and doctoral degrees awarded has grown significantly: in July 2013 there were 73 PhD students in Mathematics up from 35 in 2007; in Statistical Science there were 41 up from 25 in 2007 (some of these students being joint with other UCL departments). REF4a shows that PhD graduates have increased steadily with an average of 14 PhDs awarded per year during the REF period compared to 7 per year for the RAE2008 assessment period. It is especially pleasing to note that 2012-13 saw the largest number (23.5) of Mathematical Sciences PhDs ever awarded at UCL.

3. UCL's RAE2008 Mathematical Sciences submissions all had the ambition of increasing research funding from EPSRC. This has been achieved with the EPSRC component of grant income held by Mathematics and Statistical Science increasing from £3M in Jan 2008 to £10M in April 2013 (EPSRC GoW). Alongside this, we have also increased funding from other bodies such as NERC, ERC and the Wellcome Trust.

4. The national and international profile of UCL Mathematical Sciences has been considerably raised by hosting research meetings and workshops both at UCL (e.g. BAMC in 2012, an international meeting on Algorithmic and High Frequency Trading and numerous LMS and EPSRC

workshops) and by organizing many Newton Institute programmes and similar programmes at Mittag-Leffler, MSRI and Oberwolfach. As detailed later, staff hold a diverse range of positions on national and international advisory and professional bodies, review panels etc. Service of this kind is recognized by the Departments in workload allocation and given incentive through the promotion process.

Future strategic aims and goals

UCL aims to become one of the leading institutions in Europe for research, learning and teaching in Mathematical Sciences. To achieve this we have set ourselves the following ambitious but realistic objectives:

1. Aligned with UCL's institutional research strategy, Mathematical Sciences will continue to foster leadership in discipline-based research. By this we mean both recruiting established research leaders and developing its present researchers into leading mathematical scientists. A key ambition in recruitment is to bring to UCL mathematical scientists who have, or have the potential to, produce world-leading research which is significant (i.e. 'deep') and rigorous. It is made explicit that research quality is far more valued than quantity.

2. Application: UCL has multi-disciplinary research strengths and Mathematical Sciences intends to take full advantage of this by continuing and enhancing its interdisciplinary research. Particular examples of this include the future collaboration with the soon-to-be-opened (2015) and closely-located Francis Crick Inst. (biomedical research, an area in which UCL Mathematical Sciences already makes significant research contributions); the recently launched (2013) UCL Centre for Inverse Problems which brings computer scientists, engineers and neuroscientists together with mathematicians and statisticians; Institute of Risk and Disaster Reduction; Energy Institute and SECReT (security science). UCL has identified 4 areas of multi-disciplinary research priority (''Grand Challenges'') and promotes these by providing, for example, small grants to initiate and support collaborations. Mathematical scientists have been involved in the two Grand Challenges of ''Sustainable Cities'' and ''Global Health'' and we aim to take further advantage of such opportunities.

3. We are determined to sustain, and build upon, our success during the REF period of increasing PhD student numbers and graduates. Special attention will be given to increasing the proportion of female PhD students, with actions being detailed in both departments' Athena SWAN award applications submitted November 2013. We are excited to be leading the new joint UCL-Imperial-King's EPSRC CDT *Geometry and Number Theory at the Interface*. From 2014 the CDT will admit 73 PhD students over 5 years and its initial director will be UCL's Michael **Singer**. First year cohorts will receive their training while being based at UCL. The CDT will call upon a supervisory pool of 40 outstanding researchers across the 3 institutions; the success of the bid was helped by UCL's building of an excellent new group in geometry and topology (7 post-RAE2008 appointments in this area: see Sec. **c 1**). Mathematicians and statisticians with research interests in environmental modelling were also involved in the successful London-wide NERC DTP bid (led by UCL) in 2013. From 2014-15 this will admit 24 PhD students per year (for 5 years), some of whom will undertake research in areas in which UCL mathematical sciences has a strong track record e.g. modelling of ocean and atmospheric fluid dynamics (**Esler**, **ER Johnson**, **McDonald**). Continued and increased engagement with UCL multi-disciplinary centres is also key to growing student numbers. The highly successful strategy of funding PhD students as Teaching Assistants (TAs) will be extended. This scheme funds fees and stipend for PhD students for 4 years and in return TAs spend about 25% of their time teaching (e.g. giving tutorials, problem classes and ancillary courses). The scheme provides valuable teaching skills for such students and has significantly helped to reduce the teaching loads for staff since RAE2008. The number of TAs awarded to new PhD students in Mathematics has grown from 2 per year in 2008-12, 3 in 2012-13 to 5 in 2013-14. In Statistical Science a mixture of TA studentships and other Departmentally-funded studentships has been used, with numbers fluctuating around an average of just over 2 per year since 2008. Also two 'UCL Impact Studentships', with 50% funding from UCL and 50% from industry (Xerox), began in 2012. We aim to increase the number of such impact studentships by

seeking further industrial partnerships.

4. Nine ECRs have been appointed since RAE2008. We aim to recruit further excellent ECR staff with the aim of reinforcing and expanding research themes, as well as sustaining the overall vitality and sustainability of Mathematical Sciences at UCL. Increasing staff numbers has the additional benefit of enabling more frequent, and longer, sabbaticals. Mathematics has had particular historical research strengths in, for example, analysis and fluid mechanics and we are determined through targeted recruitment to continue to be a UK leader in these areas. Equally, the new research areas which have been built-up in recent years (e.g. geometry, financial mathematics, inverse problems, numerical and computational mathematics) will also be enhanced: e.g. 2 new positions at Lecturer/Senior Lecturer level in financial mathematics have been advertised in autumn 2013. Statistical Science having particular strengths in Bayesian and computational statistics, stochastic processes such as time series, random fields and continuous time processes will be reinforced as well as expanded to newer areas such as the analysis of networks.

5. In autumn 2013 the Department of Mathematics will advertise the inaugural Clifford Fellowship (named after WK Clifford who held a Chair at UCL from 1868 until his death in 1879, age 33) scheme aimed at attracting top early career researchers. This ongoing Fellowship is similar to schemes operated by other leading UK departments and we are excited to be able to attract and foster the career-development of leading early career researchers in mathematics (a key UK career transition point as identified by the 2010 International Review of Mathematics). The first 3-year post will be advertised in both pure and applied mathematics with subsequent posts alternating between pure and applied mathematics. We believe that attaching the name Clifford to the Fellowship will make it attractive to potential donors and we will be pursuing the possibility of expanding the scheme through both institutional and philanthropic support.

6. It is an institutional commitment, now in its planning phase, to concentrate research in Mathematical Sciences by co-locating the two departments of Mathematics and Statistical Science. In addition to significant research benefits, with a good example being the recent appointment of **Kiraly** (ECR) in Statistical Science who has interests in combinatorics aligned with those of mathematicians **Barany** and **Talbot**, co-location will enhance the experience of undergraduates, many of whom take courses in both departments.

7. A natural objective is for UCL Mathematical Sciences to take advantage of its outstanding location including excellent transport links to the rest of the Europe and the world, and London's concentration of leading mathematical researchers to attract world class mathematicians to visit UCL. Provision of high quality research space for visitors in any new co-located accommodation is important to realizing this objective, as is working with UCL's accommodation office to find suitable residences for such visitors.

8. Continue to increase the total value of research funding and, in particular, increase the proportion of funding income from non-EPSRC sources e.g. Wellcome Trust, NERC, Industry (including aeronautical and financial industries) and ERC. Sharing of good practice with previously successful applicants from both within Mathematical Sciences and other UCL departments, and the further freeing up of staff time to enable preparation of such applications will help achieve this aim. We also aim to increase our 'share' of the EPSRC Doctoral Prize for post-PhD researchers. This is an excellent way of retaining and bringing leading post-doctoral researchers in Mathematical Sciences to UCL, and we are pleased to note a recent success in recruiting an outstanding new PhD from Warwick to work in geometric group theory with **Wilton** in early 2014.

c. People, including:

i. Staffing strategy and staff development

The considerable expansion in research-active staff noted in Bthe previous section is a result of explicit institutional policy to boost research in the Mathematical Sciences and is robustly financially underpinned by strong and sustained (over many years) recruitment of well-qualified UG

and MSc students (including a large proportion of non UK/EU students) to programmes in mathematics and statistics.

Research in mathematics takes place in, and across, the following groups: pure and applied analysis; geometry and topology; mathematical modelling in biology, finance, industry and society; fluid mechanics; mathematical physics; algebra, number theory and combinatorics. In Statistical Science the groups are computational statistics; multivariate and high dimensional data; stochastic modelling and time series; biostatistics; and general statistical theory and methodology. In both departments there is considerable interaction and cross membership within research groups.

Smyshlyaev replaced **Smith** as Head of Applied Mathematics in 2010 and **Parnovski** replaced Ball (left for U. Warwick in 2011) as Head of Pure Mathematics in 2012. This has enabled **Smith** to devote more time to research and his Directorship of the London Taught Course Centre (LTCC). Both Heads of Pure and Applied, together with the Head of Department (**Vassiliev** from RAE2008 to 2011; **McDonald** from 2011), have responsibility for monitoring research activities and output in Mathematics, along with overseeing new appointments and developing research strategy. In Statistical Science the HoD, (Sweeting RAE2008 to 2010, **Isham** 2010-2011, **Fearn** from 2011) has overall responsibility for these matters, with input from the Director of Research (**Olhede**) on strategy and from the leaders of the various groups.

In Mathematics, posts have mostly been advertised in either 'pure' or 'applied' mathematics with the most outstanding candidates appointed irrespective of their research field. The majority of first choice candidates accept our offers. This has naturally led to the creation of an excellent new group in geometry and topology with the following post-RAE2008 appointments: **Evans** (ECR), **Lotay**, **Louder**, **Schulze**, **Singer, Wendl** and **Wilton**. Since RAE2008, Mathematics has reinforced its outstanding group in analysis with the following appointments: **Betcke**, **Burman**, **Kamotski**, **Oksanen** (ECR) and **Smyshlyaev** who join established members Ball, Csornyei (left for U. Chicago in 2011), **Halburd**, **Kurylev**, **Laczkovich**, **Parnovski**, **Petridis**, **Sidorova**, **Sobolev** and **Vassiliev**. The post RAE2008 staff have strengthened the 'applications' side of this group: multi-scale analysis of PDEs, numerical analysis and inverse problems. **Zerbes** was recruited in 2012 to reinforce research in number theory (joining **Hill**, **Petridis** and **Yafaev**).

Alongside the appointments outlined above, Mathematics has sought to take advantage of current interest in specific research areas via targeted investment in the following research directions: the creation of a new group in financial mathematics comprising of Shaw (0.5 FTE Chair appointed 2010 jointly with Computer Science, left for industry position in 2012), **Cartea**, **Marinelli** and **Macrina**. Following the group's successful introduction, two further posts in this area are being recruited in autumn 2013. **Burman**'s appointment to a chair in computational mathematics in 2013 was a result of a College-wide initiative to boost its expertise and provision in research computing. **Oksanen** (ECR) was appointed Lecturer in a post related to the mathematics of inverse problems and joins the pure and applied analysis group. His appointment is in support of the new (2013) UCL Centre for Inverse Problems. Zaikin (returned to UoA 1: Clinical Medicine) was appointed to a Chair in Systems Medicine shared between Mathematics and UCL's Inst. for Women's Health. This joint post is aligned with the interdisciplinary research ambitions and has boosted numbers of PhD students in this area e.g. Zaikin has supervised 2 Mathematics PhD students to completion so far and is presently supervising a further 3.

UCL's RAE2008 Statistics submission contained the following objective: "nurture the evolving disciplinary and interdisciplinary strengths within our research themes while also seeking opportunities to grow important new areas of research". Key appointments since RAE2008 which have helped realize this objective have been those of **Girolami** (2010) and **Wolfe** (2012) to chairs. **Girolami** is now director of the cross-disciplinary Centre for Computational Statistics and Machine Learning and his appointment, together with those of **Beskos** and **Silva** in particular but with the involvement of several other staff, has established the department as a UK leader in this area. **Wolfe** is a more recent arrival, but with departmental and institutional support is growing the area of big data in general and network analysis in particular. Other appointments (**De Iorio** as Reader, **Baio** and **van den Hout** as Lecturers) have strengthened biostatistics, where we intend to grow

collaboration with the Crick Institute.

Recruitment in Statistical Science has been made easier by the introduction in May 2011 of a market supplement for grades from lecturer to professor. This has enabled the Department to compete effectively in a market where demand outstrips supply, and has particularly helped with recruitment from overseas. The provision of start-up funds for senior appointments in both departments and UCL generous relocation supplement (£9K) has also helped recruitment.

During the REF period, our departments have made the following international appointments: **Cartea** (Madrid), **Cotar** (Toronto), **Evans** (ECR, ETH Zurich), **Kiraly** (ECR, TU Berlin), **Manolopoulou** (ECR, Duke), **Marinelli** (Bolzano), **Oksanen** (ECR, Washington), **Peters** (Sydney), **Schulze** (Free U. Berlin), **Wendl** (Humboldt, Berlin), **Wilton** (Caltech) and **Wolfe** (Harvard).

The departments are determined to promote equal opportunities and diversity among their staff and have taken action to do so. Since 2011 all appointing panels in Mathematics have had at least one female member, and from spring 2013 it has been a UCL requirement that all appointing panels have 25% female membership. From 2012 a positive action statement has appeared on *all* academic appointments in Mathematics. Both departments submitted Athena SWAN award bids in autumn 2013, and Mathematics took part in the LMS good practice benchmarking survey in 2012 leading to the report *Advancing Women in Mathematics: Good Practice in UK University Departments* launched at the House of Commons in 2013. Both departments have signed up to the LMS Good Practice Scheme and display the good-practice logo on the homepages and in their recruitment advertisements. **McDonald** was a member of UCL's institutional team which successfully renewed the University's Athena SWAN Bronze award in 2013 and gave a presentation on being an LMS good practice supporter to the Athena Forum at the Royal Society in September 2013. **McDonald** and **Wolfe** belong to UCL's '50:50' gender equality committee. In addition to 12 months maternity leave, the UCL's Gender Equality Scheme provides for one term of sabbatical leave without teaching commitments for research active academic staff returning from maternity, adoption, extended carer's, or long term sickness leave. For example, **Wilson** was given reduced teaching and administrative duties upon returning from maternity leave in Jan 2013 so that she could concentrate on research. **Herbots** benefited from an EPSRC Post-Break award to fund a sabbatical term in autumn 2012 after duties as a carer impinged on her research.

Ten staff hold, or have held, Fellowships in the departments during the REF period: **Wolfe** (EPSRC Established Career Fellow 2013-18), **Girolami** (EPSRC Established Career Fellow 2012-17), **Lotay** (EPSRC Career Acceleration Fellow 2011-14), **Wilton** (EPSRC Career Acceleration Fellow 2011-16), **Betcke** (EPSRC Career Acceleration Fellow 2011-14), **Talbot** (Royal Soc. URF 2005-13), **Halburd** (EPSRC Advanced Res. Fellow 2005-10, held at Loughborough until 2007), **Wendl** (Royal Soc. URF 2011-2016), **Olhede** (EPSRC Leadership Fellow 2010-15), **Byrne** (ECR, EPSRC Postdoctoral Fellow 2013-16).

With the exception of **Byrne** (ECR), all REF Category A staff have permanent contracts, including those on Fellowships who hold proleptic lectureship appointments. The successful strategy here is that by offering permanent positions we have been able to attract outstanding young mathematical scientists i.e. **Betcke**, **Lotay**, **Wendl** and **Wilton**.

Newly appointed staff are given reduced, typically 50%, teaching loads and minimal administrative responsibilities in their first year. Those on Fellowships are not required to teach, but may do so if they wish. Indeed this option has been taken up by all such Fellows in Mathematics and has led to well-received final year courses being introduced aligned to research interest of the department (with consequent benefits for inspiring potential PhD students) e.g. Riemannian Geometry; Topology and Groups. All new staff at lecturer level are assigned mentors from within their departments, and are encouraged to attend a formal induction day hosted by the Provost and members of UCL's Senior Management Team. Each department has their own local induction and welcome events. A range of courses are offered to new staff related to teaching, supervision of research students, preparing grant proposals etc.

Both departments have promotion committees (with, from 2012, at least one female member in the Mathematics promotion committee) which meet annually to consider all staff for promotion. Staff are also encouraged to approach HoDs to discuss promotion possibilities and they also have the right to put themselves forward for promotion without department support should they wish. The College puts on workshops for potential promotion candidates and has uploaded these to its website. Promotion, considered annually, is entirely merit based with no quotas imposed. UCL is ready to recognize and reward exceptional performance through early promotion e.g. **Betcke** promoted to Reader in 2013.

Staff with significant research funding enabling them to 'buy-out' their teaching for significant periods (e.g. **Yafaev**, 5-year ERC Starting Grant awarded 2012; **Olhede**, EPSRC Leadership Fellowship) have been deliberately 'replaced' by permanent appointments (rather than fixed-term). Again the strategy here is to boost long-term research capacity by advertising permanent posts aimed at attracting excellent researchers.

Staff returning from significant administrative responsibilities are given a 6-month sabbatical and then light teaching and administrative loads for a further six months to enable them to reinvigorate their research e.g. **Vassiliev** upon stepping down as HoD of Mathematics in 2011. Equally, staff with significant administrative responsibilities are assigned light teaching loads e.g. **Sobolev,** Chair of the Exam Board in Mathematics has no teaching in 2012-13. In Statistical Science recent Heads of Department (**Isham**, **Fearn**) have been assigned light teaching loads.

Increased grant funding has led to a welcome increase in PDRAs in Mathematical Sciences. In September 2013 the departments enjoy their greatest ever number (23) of PDRAs. PDRAs have their own shared office spaces and each has a desk and computing facilities. They contribute to the research culture in the departments in a major way in their interaction with both staff and PhD students. In Mathematics they are strongly encouraged to participate in departmental teaching activities, which not only benefits their own career development but, importantly, has helped reduce teaching loads of permanent staff. UCL runs a professional development programme specifically for PDRAs which implements the Concordat to Support the Career Development of Researchers.

ii. Research students

Funded PhD studentships in the Mathematical Sciences at UCL are extremely competitive: it is rare for applicants without a high 1st (i.e. over 80%) to be offered any financial support for a PhD in Mathematics. Each year the departments advertise widely to attract applications from the brightest final year undergraduates in the UK and beyond, and take part in a well-attended MAPS Faculty Postgraduate Open Day. Recruitment events aimed at our own UGs and those from across the UK are also held e.g. the Geometry and Topology open day held in autumn 2012. We are determined to increase the number and proportion of female PhD students and our 2013 Athena SWAN award submissions have detailed a number of actions for achieving this. Potential students are encouraged to identify and if possible meet with potential supervisors before submitting a formal application ensuring there is a genuine match of research interests between students and supervisors.

For the last two years Mathematics has streamlined its funding allocation process; we advertise both the EPSRC DTG and all other PhD funding opportunities simultaneously (these consist mainly of TAs and college scholarships). Around 20 applicants are then invited to interviews, which take place over two days with a panel of members of the department. UCL's internal college scholarships are very competitive and Mathematics is consistently awarded more than its fair share from this source due to the excellence of the candidates we attract. In Statistical Science the recruitment process is a more continuous one, with available funding being matched to the best applicants throughout the year. In 2012-2013 Mathematics had 21 new PhD starters, its highest intake ever, and Statistical Science had 15. Conversion to CASE awards has been very good, recent industrial partners include the Met Office, NAG and Total Sim. Other industrial partners who

have sponsored 50% of the cost of PhD studentships in Statistical Science are Xerox and PeerIndex.

Interdisciplinary PhD supervisions thrive, e.g. with CoMPLEX (Life Sciences), SECReT, the CDT in Financial Computing based in Computer Science, UCL Institute for Origins (Theoretical Physics), the Energy Institute, Centre for Advanced Spatial Analysis, Biochemical Engineering, Medical Physics, Space and Climate Physics, Geography and the Institute of Risk and Disaster Reduction. In both departments PhD students are balanced fairly equally between theoretical and applied research: there are no formal quotas in this respect but consistently good applicants are found across the range of research areas so this balance is naturally maintained. Relatively junior staff are actively encouraged and enabled to take on PhD students when possible e.g. **Sidorova** and **Marra** (ECR) each had 2 new PhD students start in 2012.

UCL is the leading partner in the London Taught Course Centre (LTCC), with **Smith** being the director, and **Fearn** coordinating the statistics courses. Through this we make a significant contribution to the UK PhD training landscape. Staff from both departments contribute many of the LTCC courses which are open to all UK PhD students. Examples of courses given by UCL staff include **Ovenden**'s 2009 course on lattice-Boltzmann methods (joint with Dellar, Oxford), **Boehmer**'s 2011 course on gravitation and cosmology, **Vanden-Broeck**'s course on nonlinear free surfaces (2010 and 2012); **Talbot**'s course on probabilistic method (2012) and **Isham**, **Nelson** (ECR) and **Cotar**'s course on stochastic processes (running from 2007).

Within the Department of Mathematics we offer postgraduates a number of seminars (often in collaboration with other London universities such as the “London Number Theory Seminar” and “London Analysis Seminar”). Attendance at relevant seminars including our pure, applied and postgraduate seminars is compulsory for research students. Moreover students upgrading from MPhil to PhD are required to speak at the Postgraduate seminar. In Statistical Science there is a weekly series of departmental seminars, as well as a specialised series in , biostatistics, as well as others run via the Centre for Computational Statistics and Machine Learning. The latter have included two series of Masterclasses with high-profile outside speakers e.g. Wasserman (Carnegie Mellon). The Statistical Science PhD students run their own seminar series, where recently upgraded (MPhil to PhD) students give talks to students and staff.

The research and training progress of each PhD student is recorded in their personal on-line UCL Student Research Log: this enables both supervisors and departmental graduate tutors to easily monitor students’ progress in research and training. Each training activity has an associated points value (with 1 point equal to half a day of training). For example, preparing and presenting a paper at a conference would earn a student 3 points. All research students at UCL are expected to engage in training equivalent to two weeks per year. Completion of the Student Research Log and the training requirements are mandatory for all PhD students.

PhD students are strongly encouraged to attend and present research at conferences, meetings and workshops, with such attendance being fully funded. Typically every graduating student has presented their research at least once at a UK or international meeting or workshop. Recently, presentations by UCL PhD students have been given at BAMCs, Oberwolfach, UK-Japan Mathematical Forum, IUTAM Symposium in Japan and the Symposium on Computational Geometry in Brazil, 2012 ISI Meeting in Instanbul, Int. Meeting in Statistical in Climatology Korea 2013, Workshop on Analysis of High Dimensional and Functional Data, California, 33rd Annual Conf. Int. Soc. Clinical Biostatistics, Norway. PhD student Hunt (supervised by **Vanden-Broeck**) won a prize for best presentation at the IMA Conference on Nonlinearity and Coherent Structures in Reading 2011. PhD student Damoulas (supervised by **Girolami**) was awarded the 2012 Classification Society Distinguished Dissertation Award.

Outside of the departments there are two main additional sources of training courses for research students in the Mathematical Sciences: the London Taught Course Centre (LTCC) and the UCL Graduate School. LTCC courses span the spectrum of pure and applied mathematics and statistics. The aim of these courses is to significantly broaden the mathematical education of

students (rather than provide thesis specific content). Courses are offered at two levels: basic and advanced. Each course typically consists of 5 2-hour lectures followed by an extended written assessment. Students are also offered timely one-day intensive courses in topics of interest. All 1st year PhD students are required to take 4 LTCC courses which is deemed equivalent to 100 hours training (including coursework, preparatory reading and examinations). Students are then expected to take a further 3 LTCC courses over the next 2 years. Statistics PhD students also attend APTS courses.

The UCL Graduate School offers a wide variety of skills training with courses ranging from entrepreneurship (in partnership with the London Business School) to teaching, writing, IT, public engagement and communication skills. Both departments and the Graduate School offer generous funding for students to attend and present papers at conferences.

A further source of training is via Knowledge Transfer Network Internships for PhD students, these have enabled students to spend extended periods with industrial partners including QinetiQ, National Grid, VR Technology and Unilever.

d. Income, infrastructure and facilities

The main source of income to the departments is generated through recruitment of large numbers UG students (e.g. 315 new first year UGs in 2013/14). This level of recruitment has been stable since RAE2008 while admissions standards have steadily increased to the point where admission to mathematics degrees now requires A*A*A (with A* in both Mathematics and Further Mathematics) or A*AA + 1 in STEP. Such stable, steady recruitment has provided a sound financial base which has helped realize the research ambitions detailed in Sec a. and financially underpin the ambitions of UCL Mathematical Sciences research.

Research income has increased considerably since RAE2008. There are several reasons for this: (i) during the REF period our recruitment strategy has resulted in excellent new staff who have been successful in obtaining grants since arriving at UCL e.g. **Beskos**, **Betcke**, **Baio**, **de Iorio**, **Girolami**, **Lotay**, **Marra** (ECR), **Nelson** (ECR), **Silva**, **Singer**, **Wendl**, **Wolfe** and **Zerbes** (ii) Concomitant with increased staff levels has been a reduction in teaching loads (e.g. since 2008, a typically teaching load for a 1 FTE staff has gone from 3 to 1 or 2 lecture courses per year) enabling more time to be dedicated to research and the taking of more frequent (and longer) sabbaticals. This, in turn, has enabled more time to be devoted to grant preparation leading to increased income. (iii) UCL has provided an excellent team of 'research facilitators' who work closely with departments in providing, for example, advice and help in completing research proposals, arranging mock interviews for Fellowship candidates with notable subsequent successes in **Byrne** (ECR), **Girolami** and **Wolfe**, conduct regular meetings to discuss funding strategies and disseminate information about new opportunities. The departments have also, from 2010, introduced a system of peer review of research proposals prior to submission. Administered by **Olhede** and **Halburd** in Statistical Science and Mathematics respectively, this has led to improved quality of proposals (as evidenced by increased grant income) and the sharing of good practice in the preparation of funding applications.

It is noteworthy that in (i) of the above paragraph, the following hold, or have held, EPSRC first grants during the REF period: **Beskos**, **Marra** (ECR), **Nelson** (ECR) **Silva** and **Zerbes**. Success at this career stage is important and is a strong indicator of vitality and sustainability.

Other funding highlights include **Yafaev**'s 5 year ERC Starting Grant (2012, *Some Problems in Geometry of Shimura Varieties*); **Singer**'s recent EPSRC grant (2013, *Moduli space compactifications and manifolds with corners*); and **Girolami**'s shared (with Glasgow) EPSRC Programme Grant *A Population Approach to Ubicomp System Design.*

Evidence of interdisciplinary collaboration is provided by Mathematical Science's grant portfolio *e.g.* **Page**'s Wellcome Trust Senior Investigator Award (with Briscoe, MRC) for her work on *Regulatory dynamics of vertebrate neural tube development;* **Betcke**'s MRC grant as co-I (with Holder, UCL Medical Physics) on *Early thrombyotic intervention in acute stroke by imaging with electrical impedance tomography* and as PI on a EPSRC grant with NAG as an industrial partner*;* **Smith** is co-I on a multi-million pound RCUK grant awarded to UCL's Energy Institute to establish an *Energy Epidemiology Centre;* **Chandler** is leading a £2M NERC grant on *Probability, Uncertainty and Risk in the Environment.*

UCL Library has support of research as one of its key performance indicators. Through substantial funding UCL has one of the finest digital library offerings of any university in the UK, this being particularly relevant to UCL's Mathematical Sciences whose research spans many disciplines. The library is open 24 hours a day during all 3 terms and intervening vacations and opening hours will be extended over the summer break. Future multi-million pound plans for the library include consolidating the Main and Science libraries onto one central site delivering a modern library covering all subject areas.

UCL has invested heavily in research computing (the Legion cluster) and is a member of the e-infrastructure South Consortium awarded a £3.7M grant by EPSRC to establish two 'tier 2' regional HPC facilities. **Guillas**, a statistician, and his group, have used Legion to test uncertainties in climate models and the e-infrastructure South Consortium cluster to run weekly models of tsunamis in a project jointly funded by NERC and the insurance industry. In 2012 UCL launched a Research Software Development team: a group of professional software developers with expertise in designing, constructing and maintaining software for academic research. The group is available by open calls for proposals, for consultation and collaboration with researchers who are creating their own software and has had interactions with mathematics researchers.

All staff and PhD students are provided with a desktop or laptop computer and each department has a full-time systems administrator. Mathematics has from 2011 invested significant funds (approx 70K) using a combination of a successful EPSRC Small Equipment Grant bid in 2012 and local funding, to set up a new local cluster network (6 nodes in Jan 2013) for use in computationally intensive research in the department e.g. inverse problems arising in imaging, computational combinatorics and computational fluid mechanics. The cluster is such that it can easily be added to, as and when funds permit and use demands. A special air-conditioned room was created in 2010 to house most of the department's computing resources. Mathematics has in 2012 invested resources in modernising its outdated linux network to the latest version of Scientific Linux. Statistical Science has set up a similar cluster to that in Mathematics for use by the computational statistics group.

Modest profits earned from hosting meetings (e.g. BAMC 2012) have been earmarked to fund conference and workshop attendance by staff and PhD students; along with investment in new facilities in the mathematics common room which have created a convivial space which is the focus for interaction for staff and visitors.

The expansion of staff and PhD students has inevitably led to pressure on the accommodation, but new space has been found in both departments ensuring that all PDRAs and PhD students have their own desk space. Most staff have individual offices following investment by the departments in converting small teaching spaces into research offices. A UCL conference fund exists for staff and PhD student use and the departments prioritise their own funds to enable both staff and students to attend conferences to present their research.

Both departments welcome researchers from other institutions and provide shared office accommodation for visitors with desk, IT and library facilities. It is an important objective (see objective 7, page 3) for UCL Mathematical Sciences to exploit its convenient London location and also London's concentration of world-class Mathematical Sciences researchers, to become the 'first-choice' base for high-profile international mathematicians and statisticians when visiting the UK (see Sec a.). During the REF period visitors to the departments staying longer than a week

have included Jitomirskaya (Irvine), Avila (Paris), Barsegian (Marie Curie Fellow, Armenia), Reid (Toronto), Pastur (Kharkov).

e. Collaboration or contribution to the discipline or research base

Collaborative and interdisciplinary research is strongly encouraged and supported. UCL is especially well set-up in this regard and mathematicians and statisticians engage in many multi-disciplinary centres. The primary example is CoMPLEX (**Olhede** is deputy director), an EPSRC doctoral training centre which has been operating since 2003 and brings together life and medical science with the mathematical and physical sciences. **Baigent**, **Girolami**, **Herbots**, Olhede, **Page**, Seymour (retired 2010) and **Smith** have supervised CoMPLEX PhD students during the REF period. As mentioned in Sec. c.2 interdisciplinary PhD supervisions have also taken place in other UCL centres such as SECReT (security science), Inst. of Origins (theoretical physics), CASA, UCL Energy Institute, Biochemical Engineering, Medical Physics and Space Physics and the Inst. of Risk and Disaster Reduction (IRDR). The recent appointment of **Ross** (ECR) joint with the IRDR will strengthen the collaborations already established by **Guillas** and others.

Taking further advantage of its interdisciplinary strengths UCL has in 2013 established a Centre for Inverse Problems involving researchers in Mathematical Sciences, computer science, medical physics and neuroscience. Building upon existing strengths (**Betcke**, **Kurylev**, **Olhede**) both departments have appointed lecturers in 2013 with research in inverse problems (**Kiraly**, **Oksanen**, both ECRs). Outside UCL there are productive collaborations (e.g. CASE awards, funding for research, projects of joint interest) with industry and other research institutions, including financial companies (e.g. OpenGamma), aerospace industries (e.g. QinetiQ, AeroTex), the Met. Office, Proudman Oceanographic Laboratory, CSIRO, NCR and Xerox. It is part of our Impact strategy to foster and grow these collaborations.

Naturally there are many strong and productive links with other mathematical scientists in other UK and world institutions e.g. recent CDT joint bids involving other UK institutions. Three UCL Mathematics staff are on fractional FTE appointments and hold positions at other institutions: **Barany** (Renyi Inst. Budapest), **Laczkovich** (Eötvös Loránd University, Budapest) and **Sokal** (NYU). Sabbaticals are taken regularly and recent examples include **Kurylev** (Mittag-Leffler as AXA-IML Professor, spring 2013), **Sobolev** (Mittag-Leffler, autumn 2012), **Vanden-Broeck** (Paris, spring 2013), **Petridis** (Copenhagen, spring 2013), **Xue** (ANU, Canberra, autumn 2012), **Siddiqui** (U. Stockholm, autumn 2012) and **Beskos** (U. Singapore, autumn 2013). **Peters** is co-I on a project funded by Japan Soc. for Promotion of Science collaborating with statisticians from U. Tokyo and U. Nagoya. Significant outputs have been co-authored with non-UCL researchers e.g. Neves (Imperial) with **Lotay**, Ullmo (Paris-Sud) with **Yafaev**, Maz'ya (Linkoping) with **Kamotski**, Uhlmann (U. Washington) and Fokas (Cambridge) with **Kurylev**.

Regular seminars, some of which are recently established and reflect new research directions in the departments, are organized by staff in the following areas: applied mathematics, analysis (including London-Paris Analysis seminar), number theory, combinatorics and discrete mathematics, financial mathematics (from 2012), mathematics colloquium (from 2010), geometry (from 2011), groups and geometry (from 2011), computational statistics and machine learning and biostatistics. Speakers in London at seminars arranged by UCL staff include Novikov, Villani, Donaldson (all Field Medalists), Rodnianski, Sinai, Sunada, Its, Maz'ya, Klainerman, Solovej, K. Ball, J. Ball, Deift, Dolgopyat, Melrose, Lieb, Topping, Uhlmann, Rudnick, Avila, Jitomirskaya, Joyce, Dafermos, J. Ockendon, Pila, Craster, Movchan, Poor, Bickel and Reid.

We have deliberately sought to raise our national and international profile by hosting and organizing at UCL major conferences, workshops and meetings involving mathematical researchers e.g. 15th *European Conference on Mathematics in Industry 2008*; *BAMC 2012*; *Intl. Conf. on Mathematica* (software) 2012; *Recent Advances in Algorithmic and High Frequency Trading* 2013; Annual Meeting in *Dynamics of Rotating Fluids* 2008-13; British Society of Rheology

Midwinter Meeting 2011; LMS Short course in *Spectral Theory and its Applications* 2011; a series of 4 EPSRC-funded workshops on *Frontiers of Nevanlinna Theory* 2011-12; A one day LMS-funded Function Theory meeting 2010; IMA conference on the *Mathematics of Medical Devices and Surgical Procedures* 2012; *Joint conference of the British Classification Soc. and Working Group Data Analysis and Numerical Classification 2013.* The following have obtained funding to organize programmes at the Isaac Newton Institute: **Sokal** (*Combinatorics and Statistical Mechanics,* 2008); **Halburd** (*Discrete Integrable Systems*, 2009); Kim (now at Oxford, Non-Abelian Fundamental Groups in Arithmetic Geometry 2009); **Chandler** (*Mathematical and Statistical Approaches to Climate Modelling and Prediction,* 2010); **Kurylev** (*Inverse Problems*, 2011); Ball (Discrete Analysis, 2011); **Isham** (*Infectious Disease Dynamics*, 2013); **Parnovski** & **Sobolev** (*Periodic and Ergodic Spectral Problems*, 2015)

All staff are encouraged to play a role in driving national and international policy in Mathematical Sciences, with such activities being recognized in workload allocation and promotion cases. Staff holding leadership positions and positions on advisory bodies include the following selection: **Kurylev, Smith** and Shaw who are members of the scientific committee of the Industrial Mathematics KTN. **Singer** was elected to the Council of the LMS in 2012. He is also, from 2013, Chair of Correspondents of the INI (and hence has a place on the management committee of the INI). **Singer** was also a panel member of Deutsche Forschungs Gemeinschaft for Excellence Initiative. Ball, while at UCL, was appointed Scientific Director of ICMS from 1 Sept 2010. **Smith** is Director of the London Taught Course Centre 2008-13. **Barany** was on the committee awarding the SIAM Polya Prize 2012. **Smyshlyaev** is, since Jan 2010, a Member of Prizes Committee of the LMS and for 2009-2011 was a member of The Royal Society Research Appointment Panel. **Wilson** was secretary of British Society of Rheology, 2007-2011 and is, from 2013, a member of the IMA's Research Committee. **Betcke** was secretary of the SIAM UK & Republic of Ireland Section 2010-12. **Olhede** has been on the ICMS programme committee since 2008 and **Vassiliev** started a 5-year term on the same committee in 2013. **Isham** was President of the Royal Statistical Soc. 2011-12 (with associated role on the CMS). **Girolami** and **Wolfe** both serve on the RSS Research Committee. **Chandler** is on the steering committee for the International Meeting on Statistical Climatology. **De Iorio** serves on the board of the Int. Soc. Bayesian Analysis (2012-14).

The Department of Mathematics publishes the journal *Mathematika* and supplies most of its editorial staff with **Sobolev** being the Managing Editor. **Girolami** is editor-in chief of *Statistics and Computing*. **Sokal** is co-editor-in-chief of the journal *Annales de l'Institut Henri Poincare D: Combinatorics, Physics, and their Interactions.* Other high profile editing roles held by staff involve the following journals: *QJMAM, ANZIAM, J. Eng. Math.* (2 editors plus 1 special issue editor), *Phil Trans Roy. Soc., SIAM Journal on Mathematical Analysis, Applied Mathematical Finance, 3 editorial advisors for LMS journals, Math. Surveys and Monographs of the AMS, Mathematics Indust. Case Stud., J. Non-Newt. Fluid Mech, J. Royal Statistical Soc. C (Applied Statistics).*

From 2008 the following have served on EPSRC prioritisation panels (sometimes more than once): **Betcke**, **Halburd** (once as Chair), **Singer**, **Girolami**, **Smith** and **Vassiliev. Esler** has served on NERC prioritisation panels; **Girolami** BBSRC and MRC panels; **Kurylev** on ERC Consolidation Grants Panel; **Guillas** and **Vanden-Broeck** on NSF panels in the USA. Eleven staff in this submission are, or have been, members of the EPSRC Peer Review College during the REF period.

There are regular invitations to UCL mathematical scientists to give plenary and keynotes talks. Some examples: **Parnovski** 6th European Congress of Mathematics, Krakow (2012); **Barany** SIAM Discrete Mathematics, Austin (2011); Analytic aspects of convexity, Cortona (2010); **Vanden-Broeck** Frontiers in Applied and Computational Mathematics, New Jersey Institute of Technology (2008); Csornyei (when at UCL) International Congress of Mathematicians, Hyderabad (2010); **Sokal** Monte Carlo Algorithms in Statistical Physics, Melbourne (2010); **Page** Kavli Institute of Theoretical Physics workshop on Morphogenesis in Cell and Developmental Biology, Santa Barbara (2013); **Evans** (ECR) UK-Japan Mathematical Forum on Algebraic and Symplectic Geometry, Keio (2013); **Smyshlyaev** SIAM Homogenization and applications (2013); **Halburd**

19th International Conference on Difference Equations and Applications, Oman (2013)*;* **Vassiliev** Complex analysis and dynamical systems VI, Israel 2013*;* **Chandler** Swiss National Statistics Meeting 2011, **Hennig** Robust Statistics, Valladolid 2011, **Fearn** NIR Spectroscopy 2013, Montpellier; **Macrina** Strathmore International Mathematics Conference, Nairobi 2013 and Stochastic Processes and their Statistics in Finance, Okinawa 2013.

Parnovski's paper *Bethe-Sommerfeld conjecture* won the Distinguished Paper Award in 2008 for articles published in Annales Henri Poincare. **Girolami** was elected FRSE in 2010 and was awarded a SPIE Pioneer award in 2009, and Wolfson Research Merit Award in 2012. **Barany** was made Fellow of the Am. Math. Soc. in 2012. **Peters** was the J.B. Douglas Award Winner (by the Statistical Soc. of Australia), for excellence in postgraduate research in Statistics or Econometrics, 2008. **Manolopoulou** (ECR) was awarded 2012 Mitchell Prize by the International Society for Bayesian Analysis for her joint paper *Bayesian Spatio-Dynamic Modelling in Cell Motility Studies: Learning Nonlinear Taxic Fields Guiding Immune Response.*