Institution: Imperial College London

Unit of Assessment: 10 Mathematical Sciences

a. Overview **100% of our permanent staff are being returned in REF2014.**

This submission consists of the Mathematics Department together with statisticians based in the Department of Epidemiology and Biostatistics of the Faculty of Medicine. We are returning 108 staff (100.3 FTE): 37 Professors; 11 Readers; 12 Senior Lecturers; 18 Lecturers; 8 Senior Research Investigators; 22 Research Fellows. 33 staff submitted are Early Career Researchers.

The research interests of the staff fall into the following overlapping groups. Permanent staff are listed according to position: Professor (*P*), Reader (*R*), Senior Lecturer (*SL*), Lecturer (*L*), Senior Research Investigator (*SRI*); those appointed during the REF2014 period are marked with an *.

Algebra & Number Theory. *P:* Buzzard, Gee*, Ivanov, Liebeck, Skorobogatov; *SL:* Helm*, Pal

Analysis. *P:* Crisan, Laptev, Ruzhansky, Zegarlinski; *R:* Krasovsky*, Mijatovic; *L:* Holzegel*

Applied & Numerical Analysis. *P:* Barrett, Carrillo*, Degond*; *R:* Pavliotis; *SL:* Nurnberg

Biomathematics. *P:* Barahona*, *R:* Buck; *SL:* Colijn*, Jones*; *L:* Keaveny*, Shahrezaei*

Continuum & Fluid Mechanics. *P:* Craster, Crowdy, Hall, Holm, Mestel, Papageorgiou*, Ruban*, Schmid*, Wu; *SRI:* Atkinson, Gibbon; *R:* Berloff*, *SL:* Walton, *L:* Keaveny*

Dynamical Systems. *P:* Holm, Lamb, Turaev, van Strien*; *R:* Gibbons; *SL:* Rasmussen*

Geometry & Topology. *P:* Corti, Donaldson, Haskins, Neves*, Thomas, *R:* Buck, Coates*, *SL:* Cascini

Mathematical Finance. *P:* Brigo*, Cont*; *SRI:* Bingham, Davis; *R:* Mijatovic, Pistorius*, Zheng; *L:* Cass*, Chassagneux*, Jacquier*

Mathematical Physics & Complexity. *P:* Jensen, Parry; *SRI:* Edwards, Hewson, West; *SL:* Pruessner, *L:* Barnett*

Statistics & Biostatistics. *P:* Best, van Dyk*, Walden, Young; *SRI:* Hand; *R:* Adams; *SL:* Gandy, Heard, McCoy; *L:* Anagnostopoulous*, Bellotti*, Blangiardo*, Bottolo*, Calderhead*, Chadeau-Hyam*, Cohen*, Kantas*, Lewin*, Veraart*

Stochastic Analysis. *P:* Brigo*, Cont*, Crisan; *SRI:* Bingham; *R:* Mijatovic, Pavliotis, Pistorius*; *SL:* Gandy; *L:* Cass*, Chassagneux*, Jacquier*, Veraart*

Major achievements between 2008 and 2013 include: 65% increase in research income (£3.7M to £6.1M p.a.) with 400% increase in EU funding (£0.3M to £1.5M p.a.); 37 new permanent academic staff hired; 23% increase in permanent academic staff (62 to 76FTE); 82% increase in research staff (33 to 60); 38% increase in FTE submitted to RAE2008/REF2014 (72.9 to 100.3); 45% increase in total PhD student numbers (96 to 139); award of 3 EPSRC Programme grants and 3 new EPSRC Centres for Doctoral Training (CDT) with major departmental involvement.

b. Research strategy

Vision. The Department's overall vision is to identify the key scientific, economic and societal challenges to which Mathematics can contribute; make world-leading contributions across the spectrum of Mathematics and Statistics; solve outstanding open problems by developing fundamental new tools and, where appropriate, apply these tools to a wide range of real-world problems. This vision extends to fostering a creative and supportive culture where research students receive excellent training, postdoctoral researchers develop into outstanding independent scientists and staff at all levels realise their full potential.

The Department's own research agenda and strategy is set with the broader College context in mind: the emphasis placed on translating the highest quality science into practice worldwide being a distinctive feature of the College ethos. Translational goals, therefore, also inform the process of developing new research directions to pursue. Effective translation demands close collaboration with other disciplines; therefore developing effective collaborations within the context of Imperial College—and more broadly—is another key feature of research strategy.

To deliver these overarching goals, the basic strategy is to hire outstanding individuals within coherent research groups of such international standing, and of sufficient scale, that they attract the world's top researchers at all levels and also attract appropriate levels of research funding from research councils, charities and industry. To this end, a major part of the strategy concerns the development, and future of, existing research groups and consideration of which new research

directions to pursue. Strategic planning is flexibly implemented to ensure academic excellence in all hiring based on the very best talent available and the latest research developments.

Overall leadership of the Mathematics Department is provided by the Head of Department (HoD), Craster, advised by the Management Committee that meets regularly to decide overall policies on resources, appointments and research directions. The Department has a dedicated Director of Research, Lamb, who leads the Research Committee that coordinates bids for strategic and internal funding, and oversees the activities funded by the Department's EPSRC Platform grant.

Research position relative to RAE 2008: overview. We are submitting 100.3FTE staff (75.9FTE permanent staff) to REF2014, compared to 72.9FTE staff (62FTE permanent staff) in RAE2008. In particular we have significantly increased the number of non-permanent junior staff being submitted compared to RAE2008 and 33 staff being submitted are Early Career Researchers.

We have 37 new permanent staff in place relative to RAE2008, mixed across ranks—10 Professors, 4 Readers, 2 Senior Lecturers and 21 Lecturers—and research groups to provide leadership, succession planning and continuity, and to enable growth and renewal of groups as appropriate. To use standard categories, hires were distributed as follows: Applied Mathematics/Mathematical Physics (AMMP) 14; Statistics 11; Mathematical Finance (MF) 6; and Pure Mathematics 6. (Staff in AMMP and MF were submitted as one UoA in RAE 2008). In particular there has been substantial change of staff in AMMP (7 retirements and 2 unexpected deaths) and MF; as a result of our recruitment both groups are now in a significantly stronger research position. Pure and Statistics—ranked 1st and 2nd respectively in RAE2008, based on proportion of world-leading and internationally excellent research—have maintained and built further on their strength as detailed below. Some growth and strategic focus was facilitated by a College strategic investment in 2009 that funded 3 Chairs and 3 Lecturers in Statistics and AMMP.

Strategic Aims for Research: aims achieved and future goals. The UoA's RAE 2008 submissions detailed broad objectives in terms of developing research groups or expanding into new research areas: these have all been met and specific changes relating to the RAE objectives are marked * below. Strengthening interaction between different research groupings has been another strategic priority during the REF period; as detailed below our recent hires have already built closer links between different groupings both within the Department and with the rest of the College, and future strategy will continue to reinforce these interactions. Key future strategic aims and goals for research are summarised following the discussion of achievement of current goals.

* Strengthened the **Algebra & Number Theory** group. Gee (SL now promoted to P) and Helm (SL) were recruited from Northwestern and the University of Texas Austin respectively (in both cases following postdocs at Harvard). Since his arrival Gee has won two prestigious research prizes and an ERC Starting Grant (see Sections d & e). Together with Buzzard, Pal and Skorobogatov they now form a coherent world-class group in Algebraic Number Theory with particular strength in the arithmetic aspects of the Langlands program. The group benefits substantially from close interactions with the strong Number Theory groups at King's College and at UCL, to the extent that London now rivals Paris as the world's leading centre for the study of automorphic forms. The new Centre for Doctoral Training in Geometry and Number Theory (with King's and UCL) will exploit these London links and also lead to closer interaction with **Geometry**.

The appointment of a new chair in Algebra is currently under way, the aim being to connect the current expertise in Group Theory and Representation Theory with Number Theory and Geometry.

* Strengthened the **Analysis** group. Our increased strength in Geometric Analysis through the hiring of Neves (see **Geometry** below) strengthened existing connections (e.g. Donaldson and Haskins) between Geometry and Analysis and enabled the Department to attract Holzegel (L) from Princeton; he works at the interface between Analysis and Geometry on nonlinear hyperbolic PDEs in the context of mathematical relativity. (The 2010 EPSRC International Review of Mathematics wrote that "The part of geometry that most needs strengthening in the UK is the connection between geometric analysis and partial differential equations"). Holzegel has just been awarded a prestigious ERC Starting grant (see Section d). The hiring of Krasovsky (R), brings another new dimension to the group: rigorous mathematical analysis of random matrix models.

In future we aim to continue to build at the interface of Geometry and Analysis, reinforcing the hires of Holzegel and Neves, and leveraging the recent £1.5M EPSRC Programme Grant "Singularities in Geometric Partial Differential Equations" (with Cambridge, Warwick; see Section e for details).

Since 2008 the **Applied & Numerical Analysis** group (previously Numerical Analysis) has been

transformed with a new emphasis on Applied Analysis: the strategic aims being to create strong links with Analysis, bridge the gap between Pure and Applied Mathematics, and correct an acknowledged UK weakness (highlighted again by the 2010 EPSRC IRM) by developing a world-leading group in this area. Two very strong Chair appointments have been made: Carrillo (Barcelona) and Degond (CNRS Toulouse); Carrillo gave an invited lecture at the 2008 European Congress of Mathematics; Degond was awarded the 2013 Jacques-Louis Lions Prize. Both have been awarded Wolfson Research Merit Awards. As a result of these hires the Department is now an international leader in kinetic theory and aggregation-diffusion PDEs: it will, for instance, host the major international conference in this area, Ki-Net, in 2014. These interests complement those of existing group members: Barrett, Nurnberg and Pavliotis. Collectively the group now has the critical mass to enable it to interact closely with Analysis (as in Pure Mathematics), Stochastic Analysis and analysis in finance. Developing collaborations with application areas, such as Biomathematics, Social Science and Physics, is a key objective and will be strongly supported.

* The **Biomathematics** group has flourished (despite the 2010 death of its founder, Stark), doubling in size since RAE 2008, and has fulfilled the aim of developing interdisciplinary relationships through its involvement in centres in Systems Biology, Synthetic Biology and the British Heart Foundation (BHF) Centre of Research Excellence. Barahona's (P) move from Bioengineering to lead the group in 2011 immediately brought existing links and collaborations within Imperial to the heart of the group; he is a co-Director of the BHF Centre of Research Excellence (£3M renewed 2014-19), a co-PI on two large cross-departmental grants (£2M SABR and £2.3M LoLas BBSRC grants with Life Sciences) and also on an EPSRC Synthetic Biology multi-institutional grant (£1M). Building around this, 4 new lecturers joined the group: Colijn, Jones (both promoted to SL)—from Bristol and Oxford respectively—and Keaveny (Courant), Shahrezaei (McGill). The group, including Buck (R), now crosses many research group boundaries—topology, fluid mechanics, epidemiological modelling, complex networks and control theory.

Future strategy is to continue the recent expansion, motivated both by the general rapid data-driven move toward more sophisticated quantitative methods in biomedicine and life sciences and by the 2015 opening of the £650M Crick Institute in London. Growth will be coordinated across Imperial with the world-class Life Sciences, Medicine, Physics, Chemistry and Bioengineering departments with which the group has strong collaborations.

*To catalyse further cross-College collaboration—particularly with Imperial's world-class Engineering Departments—the RAE 2008 plan was to hire two lecturers in **Continuum & Fluid Mechanics** with an Industrial Mathematics focus. However a strategic opportunity presented itself: two Professors, Papageorgiou (NJIT, USA) and Ruban (Manchester) were appointed instead. The leadership and critical mass these hires provided were crucial to the success of the 2011 LFC-UK £5M (£4.2M from EPSRC, with industrial partners AIRBUS UK, Aircraft Research Association Ltd, BAE Systems, EADS Airbus providing £0.8M) Programme Grant in Laminar Flow Control (PI Hall) led by Mathematics and co-hosted by Aeronautics. The recent Chair appointment of Schmid (Ecole Polytechnique; associate editor of Physics of Fluids) further strengthens the group and provides succession planning for Hall and Ruban. The result is a large, vibrant Fluid Mechanics group with broad research interests across all scales from microfluidics to planetary and oceanic modelling.

Going forward, a key aim is to facilitate yet further collaborations between the Department and the Imperial Engineering Departments to complement the existing strong links with Aeronautics, Mechanical Engineering, the Grantham Institute for Climate Change and Chemical Engineering that are evidenced by LFC-UK, a Platform grant on Complex Interfacial Flows, the funding of Berloff's salary for three years from the Grantham Institute, and numerous collaborative grants including a newly awarded EPSRC CDT in Fluid Mechanics. Schmid's recent appointment will catalyse such links and also strengthen ties to Aeronautics: by leveraging our complementary skills—alongside those of industrial partners—we aim to play an important role in the substantial Government BIS Technical Strategy Board initiatives taking place in Aerospace. The Department is closely involved with climate initiatives alongside the Grantham Institute, and looking beyond REF2014, will play an important role in the very recently awarded NERC Doctoral Training Partnership, Science and Solutions for a Changing Planet and the EPSRC CDT in the Mathematics of Planet Earth. Ham has recently joined us on a 5-year NERC Independent Fellowship and from Nov 2013 Cotter (moving from Engineering) brings further expertise in climate and atmospheric modelling; these appointments augment our existing strength in this area and will

further strengthen links to the Grantham Institute, Earth Sciences and Atmospheric Physics.

The **Dynamical Systems** group is now firmly established nationally and internationally; it holds two Advanced ERC fellowships (Holm and van Strien). Following the retirements of Elgin and Moore, and Luzzatto's move to ICTP (Trieste), the group was strengthened by the appointments of van Strien (a Chair from Warwick; invited speaker at the 2014 International Congress of Mathematicians) and Rasmussen (developed internally as a Marie-Curie Fellow, then EPSRC Career Acceleration Fellow, Lecturer and promoted to Senior Lecturer in 2013). Turaev (invited speaker at 2010 ICM) was promoted to Professor in 2013. Its research is cutting-edge in Hamiltonian, low-dimensional and random dynamical systems and bifurcation theory.

Building on its critical mass, thriving schedule of workshops and short courses, and active visitor programme, the group is becoming a world-class centre in the field. Van Strien's recent ERC Advanced award will strengthen links to Pure Mathematics. The group also aims to strengthen its interdisciplinary links to Control Theory (with Electrical Engineering), Climate Change (Grantham Institute for Climate Change) and Stochastic Analysis. A workshop on Critical Transitions in Complex Systems (Mar 2013)—funded by the Grantham Institute, the Mathematics Platform Grant, the LMS and the Gordon and Betty Moore Foundation—is a model for future interdisciplinary links.

* Continue to develop Imperial as a leading world-class centre for **Geometry & Topology**: Neves (L, now promoted to P), hired from Princeton, and Coates (R), a postdoc at Harvard prior to joining us as a Royal Society URF, broaden the scope of the group, bringing new expertise in Geometric Analysis and Gromov-Witten theory respectively. Both hires have already proven extremely successful, e.g. both have since won prestigious research prizes and large ERC Starting Grants (see Sections d and e). Neves attracted worldwide acclaim for his recent proof of the famous Willmore Conjecture; he has been invited to speak at the ICM in 2014. Other major developments include an ERC Advanced Grant (Donaldson), an EPSRC Leadership Fellowship (Haskins) and the award of 2 EPSRC Programme Grants (see Section d)—Applied Derived Categories (Thomas) and Singularities of Geometric PDEs (Neves). The group has hosted a large number of world-class postdoctoral researchers funded by these grants, by internal Imperial Fellowships (Chapman and Imperial Junior Research Fellowships) and by external fellowships (EPSRC, Marie-Curie, JSPS and Royal Society). Donaldson's long-term investment in Kaehler geometry has recently paid off in spectacular fashion with his resolution of the long-standing Yau-Tian-Donaldson conjecture, consolidating the group's world-leading status in Kaehler geometry.

* **Mathematical Finance** has been considerably strengthened since RAE 2008. Following a long-term Departmental strategy to take advantage of the reputation of the College and the status of London as a world financial centre, we have developed a world-class group that combines the highest academic standards in research and postgraduate training with strong industry interactions. The hiring strategy has reflected this: two new Chairs, Cont (Columbia, USA) and Brigo (Kings) joined in 2012; both have strong academic reputations (e.g. Cont won the 2010 Grand Prix Louis Bachelier of the French Academy of Sciences) and have built strong industrial reputations through work in the financial sector: Brigo as Global Head of Quantitative Analysis for Fitch Solutions; and Cont as consultant to HSBC, the Federal Reserve, Bank of England and the Basel Committee. Brigo and Cont provide leadership to a group of younger academics also hired over the REF period: (R) Pistorius; (L) Cass, Chassagneux and Jacquier. These hires built bridges across the Department—with Pure Mathematics, Statistics and Stochastic Analysis—and with industry, both through funding of PhD students (over a third of students were industry-funded) and appointment of prominent industry research figures as Visiting Professors (see p13).

Going forward, in addition to growing our already close ties to the financial industry (see also p13), we aim to foster stronger connections with other European centres of excellence in Mathematical Finance: to this end the group recently initiated a research collaboration and exchange programme with ETH Zurich. We will also strengthen links with the Statistics group, exploiting their longstanding strength in Credit Scoring and Retail Finance: in the short-term through planned appointments in Financial Statistics, that are also aimed at enhancing our connections with the Computing Department, the Business School and industrial partners in the financial sector.

The College has coherent groupings in **Mathematical Physics & Complexity.** The Mathematics Department plays an active role here with staff committed to research student supervision and teaching in two Centres for Doctoral Training (CDTs) based in Physics—Theory and Simulation of Materials, and Controlled Quantum Dynamics—and was instrumental in the creation of the cross-

departmental Complexity and Networks Group. The strategy is to maintain a coherent Departmental group within the broader College context; the hire of Barnett (L) from Maryland (PhD Harvard) complements and builds connections to the Quantum Optics group in Physics.

* **Statistics & Biostatistics** has maintained its strength and developed into new areas. In Credit Scoring and Retail Finance, facilitated by Strategic College Investment, Bellotti (Lectureship funded by the Credit Scoring industry), Anagnostopoulos (Cambridge) and Veraart (Aarhus) joined as partial replacements for Hand, who continues with his research in the Department as an SRI. Veraart also brings links with the Stochastic Analysis group. Other lecturer appointments, Calderhead (UCL), Kantas (UCL) build on our existing strength in Computational Statistics, which is important in view of the challenges posed by Big Data and our ambitions in that area (see below). Cohen (L, IC) reinforces the group's Time Series and Signal Processing component. The grouping has further benefited from College-level strategy through the creation of the Imperial Centre for Inference and Cosmology (ICIC): an interdisciplinary centre established in the emerging area of Astrostatistics. This enabled the appointment of Van Dyk (UC Irvine; IMS Fellow; JASA editor) as a Chair, and Mortlock as a Lecturer (joint with Physics), and a further Chair and Lecturer in Physics. In Medicine, a lecturer appointment, Blangiardo (IC) in the recently established MRC-PHE Centre for Environment and Health reinforced our existing strengths in Biostatistics.

Our future aim is to further strengthen and expand the Statistics group to address the challenges of living in an information age, namely, massive data streams and the associated data-analytic problems. This will include applications in the areas of genomics, e-health, astronomy, cyber-security and financial data streaming (plans for the latter were described above in the MF grouping). We will also coordinate the Biostatistics activity between the Mathematics and Medicine groupings through further complementary hires made by joint hiring panels; a Lecturer appointed in Maths, Bottolo (incoming from Biostatistics in Medicine), has already provided coordinated strategic links with Medicine; Medicine itself is in the process of hiring a Chair and a Reader. Coordinated planning with Physics, aimed at establishing ICIC as a leading group for astronomical data analysis worldwide, is also underway.

The development of a coherent **Stochastic Analysis** group, led by Crisan, is a major internal initiative not anticipated in the RAE 2008 strategic aims: it includes 12 permanent staff straddling many other groupings and has benefited from both recent senior (Brigo, Cont) and junior appointments (Cass, Chassagneux, Veraart). This grouping, created organically by common scientific interest, is being strongly supported and will be given focus by an interdisciplinary College Centre in Stochastic Analysis and Applied Probability. The group has an active visitor programme, hosts many workshops and acts as a catalyst driving collaborative research both internally and externally, as noted later (on p11): hosting the UK Easter Probability Meeting in 2014.

Centres for Doctoral Training (CDTs). The Department's 2012 strategic pump-priming activity, in creating several departmental mini-CDTs, paid off this year with the recent award of 3 new EPSRC CDTs in which we will play a major role: Fluid Dynamics across Scales: from Micro-Flows to Aerodynamics (with Engineering); Geometry and Number Theory (with UCL, King's); Mathematics of Planet Earth (with Reading). The Department will also play a significant role in the recently announced NERC Doctoral Training Partnership, Science and Solutions for a Changing Planet based at the Grantham Institute. The Department is also actively involved with several successfully renewed CDTs: Theory and Simulation of Materials (Craster on its Research Board); Chemical Biology (Barahona on its Research Board); Controlled Quantum Dynamics. The CDT successes attest to our strength across the range of the Department's research areas, and to the strong collaborations between our research groups internally, with other groups in College and externally.

c. People, including:

i. Staffing strategy and staff development

The key factor underpinning our research culture is the quality of our staff: all are expected to be world-class researchers and highly motivated. Our priority is therefore to attract, and to retain, mathematicians and statisticians, trained at the top institutions around the world, with the potential to become international research leaders and then to provide them with the best possible environment for their research. We also seek to attract the very best postdoctoral researchers and PhD students, give full support to their subsequent career development, and help them realise their full potential. To attract the very best postdocs, the Department funds Chapman Fellows (2-year positions with light teaching); the College funds (3-year) Junior Research Fellowships: see below.

Our staffing strategy is intimately linked to the research strategy: considerable thought is given to the appropriate number of staff required within each grouping and to the level of any appointments (also taking into account exciting new research developments and opportunities for exceptional hires). Space is not unlimited, but the staffing strategy is not constrained by the physical infrastructure: as noted later (Section d) the Department has physically expanded during the REF period to allow evolution and development of groups. In addition, the interdisciplinary research group structure that Imperial excels in, enables staff to occupy, or move to, space in other Departments, e.g. the cross-departmental Complexity and Networks group is in shared space.

We take hiring very seriously: permanent academic appointments are only made to those who are believed to have the ability to rise to the level of Professor at Imperial. To ensure a rigorous recruitment process this usually involves an open seminar to the Department, individual one-to-one meetings with staff and an interview panel—consisting of academic staff chosen to ensure both appropriate expertise and diverse representation, academically elected Imperial College Consuls, Professors from other Departments, and for Professorial and Reader appointments external Professors. If we are not absolutely satisfied by the quality and fit we will restart the process.

Promotion is taken equally seriously: nurturing our younger staff and enabling their career progression is key to maintaining our research strength. Nomination is by selected senior Professorial staff tasked to explore promotion cases; informal external referee letters are sought and each case is considered by a meeting of the full Professoriate; only if strong support is found and the case is compelling is the case sent to College. A parallel self-nomination route also exists. Interviews are mandatory for promotion to Reader and Professor and follow the appointments format (externals are replaced by the Provost); mock interviews are available and exit interviews also take place to give feedback. In the (rare) event of failure a constructive and concrete plan of action, monitored at the annual review meeting, is put in place to ensure a successful future re-application; 20 non-professorial permanent staff submitted to RAE 2008 are still in post; 17 were promoted in the REF period: 6 are now Professors, 6 Readers and 5 Senior Lecturers.

Career development support at all career stages. *New permanent staff* are supported in a variety of ways including: a 50% teaching load during their first year, no administrative duties for the first 3 years, a Department-funded PhD studentship on arrival, and a tailored start-up package (for travel and equipment). Total start-up related spending over the REF period has been £1.3M.

We assign all new staff a mentor who provides support and guidance; Early Career Researchers undertake 3 years' probation (with a formal mid-term review). The Department provides full support for Research Grant applications: this includes informal mentoring from other group members, a more formal internal grant review process coordinated by the Research Committee and internal mock panels for the interview stage of Fellowship and ERC grants; this support is also available for established staff. Similar support procedures are also available to our biostatistics colleagues in Medicine. The high success rate of our incoming staff with grant and fellowship proposals (80% already have external research income) attests to the effectiveness of this support.

Established staff: The Department places considerable emphasis on reducing the administrative burden on academic staff to free up time for research. New core administrators have been hired, including a dedicated Undergraduate Liaison Officer to act as a first point of contact for undergraduates. There has been an overall reduction in teaching over this REF period bringing the typical teaching load of 3 courses per year in 2008 down to 2 in 2013.

Sabbatical leave is given on the basis of 1 term for every 6 worked. It is discretionary and is reliant upon a strong coherent research plan for the sabbatical period. It is awarded after discussion by the Management Committee, and is almost invariably granted. Over 30 staff have taken sabbatical over the REF period: destinations include Caltech, Columbia, Courant, Duke, MSRI, Princeton, Stanford, Kyoto, MPI Bonn, Heilbronn Institute, ETH Zurich, Winton Capital and NASA Langley.

The HoD meets every permanent academic member of staff for an annual one-hour individual Personal Review and Development Plan (PRDP) meeting: teaching, research (including impact), internal contribution and staff development are discussed. This considerable investment of time was instigated to ensure that the HoD accurately represents what is a large and diverse mathematical community, and understands the needs of individual staff and groupings when coordinating and interacting with the central College. These meetings also facilitate active staff feedback and constructive dialogue regarding promotions, teaching, implementation of strategies and communication of internal and external funding opportunities.

We continue to capitalise on our most capable staff, after they reduce from full-time positions (e.g. Davis, Edwards, Gibbon, Hand, Hewson), enabling them to continue research at Imperial: support involves part-time salary, office space, secretarial support, and activities include participation in research seminars, MSc courses and MSc/PhD thesis supervision and as mentors to junior staff.

PDRAs: The Department has a very large group (over this REF period it has hosted over 100) of high-quality postdoctoral researchers who play a vital part in Departmental life; to foster this community an annual postdoctoral research workshop is funded internally. PDRAs are funded by various sources including over 50 by EPSRC and 20 from EU funding. Other funders include BBSRC, EADS, Leverhulme, MRC and the Office of Naval Research. Annually the Department hires 2 or 3 prestigious and highly competitive (we regularly receive over 300 applications from all over the world each year) Chapman Fellows. Over this REF period we have hosted 19 Chapman Fellows from institutions including Bath, Bristol, Cambridge, Courant, Harvard, MIT, NASA, Oxford, Paris Sud, Stanford, UCLA and Warwick; many of them now hold permanent academic appointments in top departments (exemplars given below). In 2009 the College started its Junior Research Fellowship (JRF) scheme, a 3-year Fellowship with no obligatory teaching or administration and generous research and travel funds; the Department has won 8 such JRFs.

The Department has a dedicated postdoctoral representative, Rasmussen, whose internal progression through the Imperial ranks (described on p3) puts him in an excellent position to advise our PDRAs on all aspects of the transition from postdoc to a permanent academic position.

The College's Postdoctoral Development Centre provides a tailored programme of development courses (including one designed for women); a bespoke scheme for Imperial JRFs; career development training; one-to-one coaching and a wide range of resources for postdocs and ECRs. It received an "HR Excellence in Research" badge from the European Commission in recognition of its alignment both with the *European Charter for Researchers and Code of Conduct for their Recruitment* and the *Concordat*; it was also shortlisted for "Outstanding Support for Early Career Researchers" at the 2010 THE Awards. Specially tailored mock interview panels arranged by the Centre have proven particularly useful to junior researchers preparing for Fellowship or Lectureship interviews. Our RAs and ECRs have made full use of these opportunities: 44 attending its courses, 12 receiving one-to-one coaching sessions and 12 taking mock interviews over this REF period.

PhD students, PDRAs and research fellows in the UoA all have an excellent track record of finding permanent positions at top research universities including at Imperial itself: attesting both to the quality of staff we attract and to the quality of our career development support. Examples (beyond Rasmussen mentioned above) illustrating various career progressions follow:

Imperial PhD students: **Anagnotopoulos**, PhD '06-10; Research Fellow '10-11, Cambridge; L Imperial '11-. **Cotter** PhD '00-04; PDRA Imperial, '05-6; L Imperial (Aeronautics), '06-13; SL, Imperial (Maths), from '13. **Gee,** PhD '00-04; EPSRC PDRF Imperial, '04-7; L Harvard '08-10; Asst Prof, Northwestern, '10-11; SL, Imperial, '11-13; promoted to P '13. **Jasra,** PhD '02-5; RA Oxford '05-6; Chapman Fellow Imperial '06-8; L Imperial, '08-11; Assoc Prof, National University of Singapore, '12-. **Ross**, PhD '08-11; RA Bristol, '11-13; L UCL from Oct '13.

Chapman Fellows: **Mondello,** '07-9, Ricercatore, Rome '09-; **Panov**, '05-8; EPSRC PDRF Imperial, '08-10; Royal Society URF '10; L King's College London, '10-. **Varvaruca**, '08-10; Assoc Prof, Reading ('12 Whitehead Prize), **Zerbes**, '06-8; L Exeter, '08-12; L UCL, '12-.

Imperial JRFs: **Garretto**, '10-12; L L`boro, '12-. **Gastner**, '09-12; L Eng. Maths, Bristol, '12-.

Royal Society URFs: **Coates,** Imperial '05-present; R Imperial, '09-. **McGerty**, Imperial '07-10; Lecturer, Oxford, '10-. **Rollin,** Imperial '05-'10, Professor and Chaire d'Exellence, Nantes, '08-.

Other PDRAs: **Nordstrom**, EPSRC PDRA Imperial, '09-12; ERC PDRA Imperial, '12-13; Lecturer Bath, from Oct '13. **Obloj,** Marie Curie Fellow, Imperial '06-8; Lecturer, Oxford, '08-.

Staff with personal research fellowships won in open competition.

EPSRC Fellowships. *4 Doctoral Prizes*: Calabrese, Green, Ottobre, Sharples (4 further Prizes awarded in Sept 2013 to start 2014); *5 PDFs:* Harriss, Kaloghiros, Morrow, Panov, Segal; *2 Leadership*: Haskins, Ruzhansky; *2 Career Acceleration***:** Lotay, Rasmussen; *2 Advanced:* Buzzard, Crowdy; *1 Established Career Fellowship:* Crowdy ('13-); *1 Early Career Fellowship:* Colijn. See also p14 for list of **ERC Starting and Advanced Awards.**

MRC Biostats Fellowship: Johnston. **NERC 5-year Independent Fellowship:** Ham. **McDonnell Foundation Fellowship:** Diaz. **Leverhulme Early Career Fellowship:** Liverani. **RCUK**

Fellowship: Lewin. **6 Royal Society URFs:** Coates, Juhasz, McGerty, Panov, Rollin, Wendl. **17 Marie Curie Fellows:** Anagnostopoulou, Brini, Delgado, Doan, Gallo, Hamzi, Iacono, Ivanov, Johnson, Koltsova, Lazaro Cami, Makarenkov, Manolache, Pereira, Rasmussen, Schillewaert, Tigan. **19 Chapman Fellows**: Afsar, Busioic, Candy, Cheraghi, Groechenig, Huang, Jasra, Kim, Lazic, Lobb, Lushi, Missauoi, Mondello, Ottobre, Pannekoek, Pocovnicu, Varvaruca, Yang, Zerbes. **8 Imperial College JRFs**: Assier, Garetto, Gastner, Gonygo, Graefe, Mueller, Oyarzun, Segal.

International appointments (incoming and outgoing) and recruitment. The international competitiveness of the Department is attested to by its ability to attract an array of mathematicians from top-ranking universities worldwide; detailed information on previous institutions of our recent hires was given in Section b. Considerable effort is made to advertise as widely as possible, e.g. through AMS MathJobs, SIAM, APS, international conferences and specialist research communities: 31 of the 37 new permanent hires submitted are non-UK nationals.

As is natural in a large department there has been some staff turnover: (below AP=Associate Professor): Bartels (P, Munster), Beardmore (P, Exeter), Becherer (P, Humboldt), Brody (P, Brunel), Chen (P, Macao), De Iorio (R, UCL), Gueldj (AP, Exeter), Ho (left academia), Howard (P, John Innes Centre), Jasra (AP, NU Singapore), Juhasz (L, Oxford), Luzzato (ICTP Trieste), Montana (P, King's), Nikolov (L, Oxford), Pravda-Starov (Chaire d'Excellence CNRS, Cirgy-Pontoise, Paris), Richardson (Director MRC Biostatistics Unit, Cambridge), Sorensen (W2 P, LMU Munich), Tasoulis (Winton Capital), Thiffeault (AP, UW Madison), Yau (L, Oxford).

Visiting Scholars. Its quality and location make the Department an international hub: in the REF period we have hosted over 300 visiting scholars from all over the world for periods of at least a week and a much larger number for shorter periods. The Department supports visitors in many ways. The EPSRC Platform Grant offers travel and subsistence support for large numbers of shorter visits: a total of 58 visits since 2011. The aim is to encourage the initiation of more speculative research collaborations with the expectation that these projects will attract larger-scale external funding as they mature. Last year, we initiated the Nelder Visiting Fellowships to enable experienced researchers of high standing to visit for at least one month during term time. Fellows are expected to present a lecture series or mini-course (PG level), a Colloquium and to interact actively. This year we are hosting 5 Fellows: Chipot (Zurich), Ciocan-Fontanine (Minnesota), Kloeden (Frankfurt), Thankur (Arizona) and Van den Eiden (Courant Institute). For longer-term visits during sabbaticals we hosted e.g. Leverhulme Visiting Professors—Behrend (UBC Vancouver), Getzler (Northwestern) and Kapouleas (Brown) and Royal Academy of Engineering Distinguished Visiting Fellow—Chang (Notre-Dame).

Support for equalities and diversity. The College resources a dedicated Equalities Unit and associated support networks, including Imperial as One (race), Imperial 600 (LGBT), and Disability Staff and Student Forums. The College's leadership programme for black and minority ethnic (BME) staff, iLead, has been so successful that Stellar HE, a development programme for diverse leaders across ten higher education institutions was modelled on it. The College has also established a leadership programme for disabled staff, Calibre.

The Department formed an Academic Opportunities Committee in 2008. In 2010, we became one of the first departments to receive the Joint LMS-HoDoMs Good Practice Award (now the Good Practice Scheme). This year we were awarded an Athena SWAN Bronze Award, one of only six held nationally by Mathematics departments. (Biostatistics holds a Silver award, as does Imperial College institutionally.) The SWAN review panel praised the Department's "commitment to Athena SWAN" as reflected in part by the composition of our SWAN Self-Assessment Team: co-chaired by the current HoD and our most senior female academic, and including two former HoDs, the Deputy HoD and the Equalities Administrator from Human Resources. Integral to the SWAN Award, is a 10-point Action Plan, a third of which has already been implemented. Concrete achievements include the following: over the REF period the fraction of female PDRAs has doubled from 10% to 20%; 4 Imperial College Elsie Widdowson Fellowships have been awarded within the Department to enable female academics returning from maternity/adoption leave to be relieved of all teaching and administrative duties to concentrate on research for 12 months.

ii. Research students

The Department admitted 233 PhD students between Jan 2008 and Dec 2013 (40 since July 2013) with over 35 different funding sources: department-funded (62), EPSRC DTA fees & maintenance (54), self-funded (32), EPSRC fees only (16), and EPSRC project studentships (12). Other funding

sources include EPSRC Case, EPSRC Prizes, ERC grants, Imperial College studentships, financial institutions, foreign government scholarships and other UK research councils and charities. Over the REF period, more than a third of our PhD students in Mathematical Finance have been funded by industry, attesting to that group's strong industrial links and relevance. Over the 5-year period 2007-12, our 4-year submission rate has averaged 92% and never dropped below 87%. A 2012 survey of staff, current research students and former research students still in contact identified first destinations for 69 former PhD students: postdoc positions 39, finance industry 21, Civil Service 3, other UK industry 2, other degrees 2, no known employment 2.

The size of the PhD student body grew 45% (from 96 to 139) over the REF period. The main factor in this increase is a strategic decision to increase the number of Department-funded PhD places, in recognition of the central role that PhD students play in the research life of the Department. Funding for these places comes primarily from significant increases both in our research income (see Section d) and our teaching income (from both undergraduate and MSc courses) over the REF period. The two main funding mechanisms are currently Roth Studentships and PhD studentships associated with several departmental mini-CDTs (mentioned on p5). The Department's Roth Studentships provide a very flexible source of PhD funding: they allow us to provide competitive funding for many excellent non-UK based students who would not qualify for full funding from the EPSRC DTA and increase our pool of highly-qualified applicants considerably. The Department has greatly improved the physical environment for research students through ongoing refurbishment of research student offices and the addition of new office space.

Recruitment. The Department receives a large number (which has increased 20% over the REF period) of PhD applications—260 (68 Home, 71 EU, 121 OS) in 2012 for our roughly 45 PhD places. The research reputation of the Department attracts top students from across the world: 42 of 2012's 47 admitted PhD students have either a 1st class degree or a Distinction in their MSc (or both). Additionally, our 4-year MSci, together with our four MSc courses, provide excellent routes into a PhD as they contain very advanced courses and a steady stream of well-trained students also enters the PhD through this route. Applicants are encouraged to attend a College PG Open Day in December, in conjunction with a focused Departmental event on the same day. All strong applicants are interviewed, those from the UK in person and those from abroad using Skype. A ranked list of candidates is produced and takes into account eligibility for different funding streams, the spread of skill needed, as well as the excellence as assessed by the interviewers.

Support mechanisms. A PG Tutor provides overall support that is augmented by dedicated PG tutors overseeing research groups. All new lecturers take the course Supervising PhD Students offered by the College's Educational Development Unit. Inexperienced supervisors always have an experienced co-supervisor who must also approve the student selection and actively engage with student supervision. Except for the staff who joined us in 2013, *all* members of permanent academic staff either have a PhD student currently under their supervision or had one who completed during this REF period. Other support mechanisms include the following: PG student representation on the Staff/Student Committee; a dedicated PGR student committee; prizes for the best PhD theses; an annual research forum for PG students (with a poster competition and prizes); and a £4K annual investment in various networking and social activities. All PhD students (including self-funders) get an annual research support allowance of at least £1K.

Progress monitoring. A comprehensive monitoring and review system is used to identify potential problems at an early stage, provide support and monitor progress. All students are examined by, and meet, two independent academics at 3, 9-12 and 18-24 months, to discuss written reports and progress. Students also report on their progress and relationship with their supervisor. If progress is unsatisfactory the PG Tutor follows up and, if necessary, the PG Welfare Office notified.

Training. The Graduate School provides an award-winning professional development programme that supports our PG students with specific emphasis on their future careers. Imperial College is the only university to have won the Times Higher Education Award for Outstanding Support for Early Career Researchers twice: in 2006 for its innovative and integrated approach to supporting young academics within the Graduate School, and in 2008 for initiating a course called "Finish Up, Move On", aimed at helping students complete their PhDs and move to the next career stage.

Discipline-specific training comprises a minimum of 100 hours of taught PG level Mathematics courses normally taken from our four extensive Masters courses (plus the Statistics options from the Epidemiology Master's run by Medicine), or from the specialised PhD level courses offered by

the EPSRC-funded Taught Course Centre (TCC) and the London Taught Course Centre (LTCC). The TCC focuses on Pure and Applied Mathematics using video technology to share live lectures with Bath, Bristol, Oxford and Warwick. Our Statistics group participates in the LTCC, where students from the London area attend programmes of lectures at de Morgan House. The TCC also supports a programme of Event Days—the most recent of which, on Topology, was held here at Imperial—organised by PhD students at the host institution, to ensure that students from all 5 institutions meet face-to-face and develop a sense of a larger research community.

Many research groups have specialised programmes to support their PhD students complementing the formal course offerings. These include the student-led Junior Geometry and Junior Topology seminars; the PhD reading seminars in Algebra and Stochastic Analysis and the Number Theory study group; the Mathematical Finance group shares a programme of advanced lectures with the groups at KCL, LSE and Birkbeck that includes a programme of PhD Seminar Days; the Dynamics group, together with similar groups elsewhere regularly runs intensive workshops on specialist topics in Dynamical Systems. Research groups also organise a large number of working seminars on a more ad hoc basis: PhD students play an active role in many of these. PhD students are also encouraged to take advantage of the wide range of weekly or biweekly seminars run by our research groups: currently 15 weekly or biweekly seminars are organised.

A Department Colloquium was initiated in 2010 with a dual purpose: to hear from some of the world's leading mathematicians and to provide a venue for the whole department to meet. Speakers are specifically requested to make their talks accessible to a general PG audience and a reception follows the talk to encourage further interaction across all levels and groups in the department. Speakers include Fields Medalists Tim Gowers FRS and Wendelin Werner, Sir David Cox FRS FBA, Elliott Lieb, Yakov Sinai, Peter McCullagh FRS and Paul Embrechts.

d. Income, infrastructure and facilities

Over the REF period the Department's research volume (total grant expenditure) totalled £22.4M. Looking forward, as of the end of October 2013, the Department had £28M of active running research grant accounts, with £12M spent already and a budget of £16M remaining.

Within the £22.4M total research volume the top three sources of funding were

1. Research Councils £14.3M (£10.3M EPSRC, £1.8M Royal Society, £1.1M BBSRC +smaller)
2. European Commission £3.8M
3. UK Industry £1.9M (primarily from EADS, Shell and a variety of financial companies).

Despite relatively flat levels of Research Council funding in Mathematics nationally over the period, annual Departmental research volume has grown by 65% during the REF2014 period: from £3.7M in 2008/9 to £6.1M in 2012/13. This growth has been driven by substantial increases in the funding awarded by the following sources (funding from other sources has been relatively stable)

- Research Councils (primarily EPSRC): £2.5M/year to £3.7M/year over the REF period
- the European Commission: £0.3M/year to £1.5M/year.

The Department has seen a substantial increase in the number of longer and larger EPSRC grants being awarded to individual researchers and to research groups within the Department, especially Programme Grants. Programme Grants are a flexible mechanism to provide funding to world-leading research groups to address significant research challenges: they are intended to support a suite of related research activities focussing on one strategic research theme. The Department now holds 3 EPSRC Programme Grants:

- Laminar Flow Control (£5M, PI Hall with £4.2M from EPSRC and £0.8M from industry)
- Applied Derived Categories (£1.2M, PI Thomas)
- Singularities of Geometric PDEs (£1.5M, Neves, joint with Warwick and Cambridge).

Members of the Department have also been very successful in winning very competitive long-term fellowships funded by EPSRC or the Royal Society: Buzzard, Coates, Colijn, Crowdy (twice), Haskins, Rasmussen, Ruzhansky all held 5-year Fellowships during this REF period.

The growth in EU funding has come mainly in the form of prestigious and highly competitive ERC Starting or Advanced Investigator Awards.

- Starting Investigator Grants: Coates (€0.6M), Gee (€1.1M), Neves (€1.1), Holzegel (€1.3M).
- Advanced Grants: Donaldson (€1.5M), Holm (€1.7M), van Strien (€2.2M).

The Department was also one of 4 Mathematics Departments to be awarded a 5-year EPSRC Platform Grant that began in 2011 (£0.5M). The Platform Grant enables us to address a lack of

baseline research support where researchers, particularly those at career transitions or at cross-disciplinary interfaces, need easy access to flexible, small-scale funding to support essential research activities, especially during "funding gap" periods. The Platform Grant has already supported a large number of short to medium-term research visits (47 incoming; 18 outgoing to-date) and provided underpinning funding for a variety of Imperial-based research workshops (15 workshops funded to-date) as well as seed money for public engagement projects.

The significant increase in our research volume over the REF period noted above is due, in part, to the large number of recent hires replacing retirements. A number of relatively new staff are still settling in; given our support mechanisms, the quality of these staff and their research areas, we expect some further rise in volume despite the static levels of funding nationally. A balanced portfolio of smaller responsive mode grants will be maintained alongside individual Fellowships and the larger-scale Programme and Platform grants. Given the success of the interdisciplinary centres and groupings at Imperial, and the active involvement of many staff within them, further collaborative grants will naturally emerge and be encouraged; this will continue to be fostered by exploratory meetings with other groupings from College, for instance with Imperial Cancer Research UK Centre, and with external partners such as MoD (DSTL) and Procter and Gamble.

Current and planned investments in infrastructure and facilities. The Department occupies 4,620m^2 half of which is research space: expansion of research activity has taken place through a 12% physical expansion since 2008. Lecture space used for research colloquia, seminars, workshops and conferences benefitted from a £1.3M refurbishment early in the REF period and our flagship (Clore) lecture theatre benefited from a £0.2M refurbishment completed in September 2013. An ongoing programme of refurbishment, representing half of the Department's total office space, has created office facilities for new staff and for growing research teams—for example, the refurbishment of an additional 350m^2 for the Laminar Flow Control team. The Department has recently refurbished a further allocation of 170m^2, at a cost of £0.7M for the new appointments made as part of its research strategy. More extensive reconfiguration of the building to house the 3 recently funded CDTs and to enable the continued ability to expand research activity is currently being planned in detail, as part of a major campus-wide master planning initiative.

Infrastructure provision and operation of specialist infrastructure and facilities. The Department has access to extensive Computing facilities: at College level, over the REF period £5M has been invested in High Performance Computing (HPC) facilities with around 14,000 cores (one of the UK's largest); over 1 million jobs from Mathematics were run on the HPC in 2012 alone, ranging from Fluid Mechanics through to the FanoSearch project in Geometry. Within the Department, flexible and responsive computing support is essential: a dedicated Research Computing Support Officer is employed directly by the Department; a Computing Committee coordinates our activities and ensures we are responsive to academic needs. There is a rolling program of upgrades for staff machines. Over the REF period over £150K has been spent on computing infrastructure and computers with a dedicated server room. The facilities range from a state-of-the art GPU machine, a dedicated Linux cluster of 20+ servers, a FreeBSD cluster with up to 400 PC nodes, to specialised research clusters of servers and workstations.

Consultancies and professional services. Our academics use the College's consultancy provider, Imperial Consultants (ICON): since 2008 ICON has brokered 30 consulting projects between researchers in the Department and 21 external clients (including BAE Systems, DSTL, IBM, Fujitsu) generating £0.4M in consultancy income. A Knowledge Transfer Fellow (Adams) acts to identify opportunities and liaise with ICON. Several staff (Cont, Craster, Hand, Heard) have acted in expert witness or adjudication roles. Cont consults for the Basel Committee for Banking Reform, and the methods developed have been adopted by the Bank of England, the Bank for International Settlements and the US Federal Reserve. Start-ups also feature with Anagnostopoulos as Chief Data Scientist of Mentat Innovations (www.ment.at) based in the Imperial Incubator—a hub for innovation/entrepreneurship, that provides space for early-stage companies on campus.

e. Collaboration or contribution to the discipline or research base

Below we give a small selection of the many collaborations and interdisciplinary projects the Department is involved with, including instances of how collaboration with research users has informed research activity and strategy: over the REF period, 29% of research grants had formal collaboration with other departments or with other institutions. Departmental support to encourage collaboration includes: sabbatical leave; teaching cover to facilitate long-term secondments;

flexible travel grants and funding for incoming visitors; computer purchase; and workshop funding.

Within the Department collaborative interdisciplinary groupings such as in Stochastic Analysis are strongly encouraged. This new group has built close links across Imperial, including with the Control and Power group led by Vinter and the Intelligent Systems and Networks group led by Gelenbe from Electrical Engineering, the Business School and the Grantham Institute. Beyond Imperial the group is part of the AHOI (Aarhus, Heidelberg, Oslo, Imperial) collaborative network of researchers in Stochastics; it also has strong ties with other groups both in the UK (Oxford, Warwick, Reading) and in Europe (Ecole Polytechnique, University of Nice, ETH Zurich).

An example of both *academic and industrial collaboration* is the Programme Grant "Laminar Flow Control": a large-scale collaboration with the Aeronautics Department, Airbus, BAE Systems and others; it has been supported by infrastructure improvements—see Section d—targeted appointments (Schmid), sabbatical leave (Hall) and visits to NASA and Bombardier (the latter giving £350K funding for RAs starting in 2013). Hall and Ruban's work has become a cornerstone of Airbus UK's research in the design of laminar flow airfoils for the next generation of civil aircraft; Airbus/EADS has also seconded staff to Imperial to help translate the output into design tools.

At the *national level* the Geometric Analysis groups at Imperial, Warwick and Cambridge have joined together for a major £1.5M EPSRC Programme Grant "Singularities of Geometric Partial Differential Equations" (2013-18); international partners include University of Zurich, MIT, UW Madison and IMPA Brazil. The research area is very broad: stretching from fundamental problems in physics, to current practical issues in engineering, and to some of the most powerful techniques in topology and geometry. Although these topics appear very different, many of the biggest future developments in each require overcoming key research challenges that are remarkably similar.

International partnerships are exemplified by "BREUDS: Brazilian-European partnership in Dynamical Systems" (2013-17) and the CHASC International Centre for Astrostatistics. BREUDS a €0.7M EU grant led by Lamb, coordinates research in Dynamical Systems across a consortium of 20+ institutions. This creates closer research ties between Europe and Brazil, and places Imperial at the heart of this activity. CHASC—founded and directed by van Dyk—is a collaboration between astronomers and statisticians at UC Davis, Harvard, UC Irvine, NASA Goddard and the Smithsonian Center for Astrophysics; CHASC leads the world in the development of state-of-the-art statistical methods in astronomy, especially Bayesian methods for high-energy astrophysics.

Collaboration with other bodies. Adams and Heard are deeply involved with cyber-security research at the Heilbronn Institute for Mathematical Research (HIMR): Adams has been seconded full time since October 2011; Heard has acted as a consultant for the same period and started a 1-year secondment in October 2013. Cyber-security is a pressing problem: a 2012 UK government report estimated the damage of cyber-attack to the UK economy at £29 billion. Defending UK infrastructure is critical to the UK economy; HIMR is directly linked into the UK intelligence community. This work has also provided the opportunity to engage with the US community: Adams and Heard collaborate with Los Alamos National Laboratory (LANL) on cyber-security problems. This led to a joint patent application based on work conducted over repeat visits to LANL by Heard's PhD student. Adams, Anagnostopoulos and Heard have also worked with BAE Systems, Detica and MoD (DSTL) on cyber-security-related projects. Their affiliation to the College-wide Institute for Security Science and Technology has also initiated further internal links and College support (two PhD studentships). Flexible support enabled the hiring of Teaching Fellows to cover long-term secondments, departmental travel grants pump-primed the LANL collaboration and the departmental purchase of a GPU computer enabled the research to progress rapidly.

Further Interdisciplinary exemplars: The Department exploits various novel interdisciplinary avenues, e.g. application of Mathematics and Statistics in Medicine and Life Sciences, as exemplified by Holm's €1.75M ERC Advanced Grant "Five Challenges in Computational Anatomy"; this research project is enabling quantitative measurements of discrepancies in shape and function in human anatomy with applications to biomedical imaging, especially brain and heart imaging. Holm's work involves extensive ongoing collaborations with the Johns Hopkins Centre for Imaging Science and at other centres including Brown, Caltech, Lausanne EPFL, Paris, Singapore and Vienna. The latest annual workshop involving contributions of Holm's research group to novel methods of shape analysis, and about 60 other collaborators, was held in May at Johns Hopkins.

More broadly, the Biomathematics group has a wide range of interdisciplinary activities including large cross-departmental grants (BBSRC LoLa; SABR), and multi-institutional grants (BBSRC,

Colijn and EPSRC, Barahona and Buck); it also organises a spectrum of interdisciplinary seminars and workshops—in many cases financially supported by the Department's Platform grant—within and outside Imperial. There is active interaction with end users of their methodological innovations; these include policy and government bodies (World Health Organization, Public Health England), industry (GlaxoSmithKline, Syngenta) and other organisations (Natural History Museum). An exemplar is work by Colijn (College support via an Elsie Widdowson Fellowship) with Gardy of the British Columbia Centre for Disease Control (BCCDC), using novel mathematical summaries of phylogenetic trees to classify outbreaks of pathogens; the results are being incorporated into the BCCDCs analysis pipeline to direct public health resources efficiently.

Research Users including Industrial Users. In Mathematical Finance four visiting Professors, Tasche (Bank of England), Martin (Apollo Asset Management), Lipton (Bank of America) and Pallavicini (Banca IMI) provide direct links to industry. The monthly London Quantitative Finance Seminar—coorganised with BNP Paribas, SEBA International and Palgrave Macmillan—has become a key interface between academic research and industry: it regularly attracts audiences of over 200. Joint research projects in quantitative finance are under way with Bank of England, Bank for International Settlement, Central Bank of Norway, Citigroup, CreditSuisse, Deutsche Bank, Mediobanca and Shell. The group's research has broad impact: Cont's work has been cited as evidence in recent high-profile international lawsuits regarding the rating and pricing of derivative securities; Brigo's work led to the creation of a European exit probability index, CEPIX. Initiatives in the direction of commerce, e.g. retail banking are encouraged with the recent academic-industry workshop "Model Risk in Retail Credit Scoring" being typical; joint work with Fitch Ratings, RBS, Scorex and Business Schools on modeling bank ratings and retail credit risk is underway. The Department is collaborating with the leading French investment management firm, Capital Fund Management, to establish a high-visibility joint institute for interdisciplinary research in Quantitative Finance and Risk Management, which will address challenges in understanding financial market complexity and the modelling and management of financial risk. External funding will be in the region of £240K p.a. and will fund PhD students and PDRAs, as well as a new high-profile academic visitor programme and a staff exchange scheme.

One exemplar of how interaction with industrial partners can influence the direction of research strategy within the College and the Department, is that of Scientific Computing, where industrial partners (e.g. Rolls-Royce) identified a critical skills gap. In response an interdisciplinary Centre for Computational Methods in Science and Engineering (CMSE) was created with Papageorgiou as co-Director. The hires of Papageorgiou, Keaveny, Schmid and Degond and the internal transfer of Cotter (SL) from IC Aeronautics have provided critical mass in Scientific Computation and place the Department at the heart of such activity within the College, and also nationally and internationally. The Mathematics and Computing Departments run a joint undergraduate program, feeding into an integrated MRes and PhD research program, with the overarching goal of creating a pipeline of highly trained and highly employable computational scientists with a real mathematical background. This impacts research direction as well as training: joint collaborative research proposals between the Departments (and in Engineering more widely) are under development.

We close with a **small** selection of contributions to the discipline nationally and internationally.

Leadership in academic community including Research Councils and learned societies (selection): *Barrett*, Applied Mathematics Panellist for RAE 2008; *Buck*, EPSRC SAT for Healthcare Technologies 2010-13, LMS Council 2007-13; *Carrillo*, Member (Chair from 2014) of the Applied Mathematics Committee of the European Mathematical Society, 2010-2013, ERC Consolidator Mathematics Panel Member 2013; *Cont,* Chair of SIAM Activity Group on Financial Mathematics and Engineering 2010-12; *Donaldson*, Scientific Advisory Board for Clay Mathematics Institute 2003-present; *Hand*, President of the Royal Statistical Society 2008-10, EPSRC Technical Opportunities Panel 2008-11, EPSRC Strategic Advisory Network 2011-; *Laptev*, President of the European Mathematical Society 2007-10, Director of Institute Mittag-Leffler 2011-, Chairman of the ERC Starting Grants Mathematics Panel 2012, 2014; *Ruzhansky,* President of International Society for Analysis, its Applications and Computation (ISAAC), 2009-13; *Thomas*, Steering Committee of Isaac Newton Institute, Cambridge 2012-15; *van Dyk,* Board of Directors of International Society for Bayesian Analysis 2009-11, Executive Board, Astrostatistics Committee of the International Statistical Institute 2009-present; *Young,* Chairman of The Committee of Professors of Statistics 2010-12, Royal Statistical Society (RSS) representative Council for the

Mathematical Sciences 2010-12, RSS Chair of Research Section Committee 2013.

Leadership in industry, commerce and government (selection): *Brigo,* Director of Capco Research Institute (Capco is a global business and technology consultancy dedicated to the financial services industry); *Cont,* consultant to UK Government Office of Science 2012, New York Federal Reserve 2009-2012, Basel Committee for International Banking Reform 2013; *Carrillo,* Member of the Council of the European Consortium for Mathematics in Industry, 2005-13; *Hand,* Chief Scientific Advisor, Winton Capital Management, 2010-present**.**

Scientific Organisation (selection): *Carrillo,* co-organiser of Optimal Transport workshop, IPAM UCLA 2008 (3 months), organiser of SIAM/RSME-SCM-SEMA meeting on Emerging Topics in Dynamical Systems and PDEs, Barcelona 2010, co-organiser of Partial Differential Equations in Kinetic Theories, INI 2010 (4 months); *Corti,* co-organiser of year-long Warwick EPSRC Symposium on Algebraic Geometry, 2007-8; *Davis,* organiser of Fifth World Congress of the Bachelier Finance Society, London 2008; *Holm,* co-organiser Mathematical Modelling and Analysis of Complex Fluids and Active Media in Evolving Domains, INI 2013 (4 months); *Ruzhansky*, 7th ISAAC Congress, London 2009; *Skorobogatov,* co-organiser of Rational Points and Algebraic Cycles, Centre Bernoulli at Ecole Polytechnique de Lausanne 2012 (6 months); *Thomas,* Co-organiser of Moduli Spaces, INI 2011 (6 months); *van Strien,* co-organiser of year-long EPSRC Symposium on Ergodic Theory and Dynamical Systems, Warwick 2010-11.

Invited keynote lectures (selection): *Hand,* COMPSTAT 2010; *van Dyk,* 10th International Applied Statistics Conference 2013; *Young*, Australian Statistical Conference 2008; European Consortium for Informatics and Mathematics 2011, *Craster,* ETOPIM Marseille 2012, ISAAC 2013, *Crowdy,* Australia and New Zealand Industrial and Applied Mathematics 2011, BAMC 2012; *Holm* BAMC 2011. *Best*, 4th International IMS/ISBA Joint Meeting 2011.

Invited addresses to major international congresses:
International Congress of Mathematicians: 2010 *Thomas, Turaev*; 2014 *Neves, van Strien*.
European Congress of Mathematics: 2010 *Carrillo*, 2012 *Corti*.
World Congress of the Bachelier Finance Society: 2010 *Davis*; 2014 *Cont* (plenary speakers).

Election to membership or fellowship of learned societies: *Donaldson,* Foreign Member of Royal Swedish Academy of Sciences (RSAS) 2010, AMS Fellow 2012; *Gee,* AMS Fellow 2013; *Laptev,* RSAS 2011; *van Dyk*, Fellow of the Institute of Mathematical Statistics 2010.

Editorships (main editors only, not large boards): *Brigo,* Managing Editor, International Journal of Theoretical and Applied Finance; *Cont,* Editor, Statistics and Risk Modeling; Editor-in-Chief, Encyclopedia of Quantitative Finance; *Craster,* Joint Executive Editor, Q. J. Mech. Appl. Math.; *Degond,* Founding Managing Editor, Kinetic and Related Models; *Donaldson,* One of main co-editors for Duke Mathematical Journal, Journal of Differential Geometry, and Geometric and Functional Analysis; *Laptev*, Chief Editor, Acta Mathematica; *Papageorgiou:* One of 4 Chief Editors, IMA Journal of Applied Math; *Schmid,* Associate Editor, Physics of Fluids, *van Dyk:* Editor, Journal of Computational and Graphical Statistics (2007-09), Journal of the American Statistical Association (Reviews); *van Strien,* Managing Editor, Ergodic Theory and Dynamical Systems.

ERC Grants: *3 ERC Advanced*: Donaldson 2010-2015, Holm 2011-16, van Strien 2014-18; *4 ERC Starting:* Coates 2009-14, Gee 2012-17, Holzegel 2013-18, Neves 2011-2016.

Fellowships (additional to those already listed on p7): Maclaurin Fellowship, New Zealand Institute of Mathematics & its Applications: *Liebeck* 2008; Humboldt Research Fellowship for Experienced Researchers: *Mijatovic* 2013; Chair of Excellence Carlos III, Madrid: *Parry* 2012; Olga Taussky Pauli Fellowship to Wolfgang Pauli Institute, Vienna: *Veraat* 2012.

Awards: *Adams*, Winton Research Prize 2011; *Brigo*, Risk Magazine most cited technical author 2010, 2012; Credit collections and Risk award for contributions to the credit industry awarded to Consumer Credit Research Group headed by *David Hand* 2012.

Wolfson Merit: Carrillo, Crowdy, Degond, Donaldson, Hand, Laptev, Thomas, van Dyk, Zegarlinski.

Prizes: *Buzzard*, LMS Senior Berwick Prize 2008; *Cont*, Grand Prix Louis Bachelier, French Academy of Sciences 2010; *Coates,* Leverhulme Prize 2010; *Crowdy,* Young Researcher Award at the Computational Methods and Function Theory conference 2009; *Degond,* Jacques-Louis Lions Prize 2013; *Donaldson*, Nemmers Prize 2008, Shaw Prize 2009; *Gee,* Leverhulme Prize 2012, LMS Whitehead Prize 2012; *Neves,* Leverhulme Prize 2012, LMS Whitehead Prize 2013; *Ruzhansky*, Daiwa-Adrian Prize 2010.

Honours: *Donaldson*, knighthood (2012); *Hand*, OBE, services to research and innovation (2013).