Institution: University of Birmingham

Unit of Assessment: UoA 10 - Mathematical Sciences

a. Overview: The School of Mathematics consists of three broad research groups: *Pure Mathematics*, *Applied Mathematics*, and *Optimisation and Statistics*.

The *Pure Mathematics group (PMG)* contains three main subgroups of comparable size: *Algebra*, *Analysis* and *Combinatorics*.

The *Applied Mathematics group (AMG)* also contains three main subgroups: *Nonlinear Systems*, *Numerical Analysis* and *Biomathematics*.

Within the REF period the School has considerably diversified its activities, establishing and consolidating internationally-leading groups in several highly contemporary research areas. As a consequence the School is enjoying increasing success in all areas of its activity. This is illustrated by:

- a four-fold increase in the value of research grant awards compared with RAE 2008, including 3 ERC Starting Grants and numerous EPSRC and FP7 awards;
- the successful recruitment and retention of numerous outstanding early-career international researchers;
- a wide variety of major international esteem indicators (including two ICM2014 invitations).

b. Research strategy:

The School has responded decisively to the comments of the panel of RAE 2008. In particular, the panel noted that "research income was lower than would be found compatible with the output evidence". In response to this the School has created a number of incentives to kick-start a culture in which research grant applications have become a matter of course. This strategy, combined with a predominant recruitment policy of appointing gifted early-career researchers to Lectureships, has resulted in an almost 4-fold increase in funding capture compared with RAE 2008. In addition to the obvious financial benefits, the School's increasing emphasis on external awards/engagement strongly promotes high-quality and ambitious research, and is a key contributor to the fast-growing international academic impact and visibility of mathematics at Birmingham. The panel of RAE 2008 also noted that "there had been a considerable turnover of staff, with a number only staying a short time". The School's recent early-career recruitment policy and associated career support mechanisms have generated a vibrant, stable and committed group of mathematicians.

In the REF period the School has significantly improved its position in several fundamental respects:

- the **research income (awards) has increased dramatically** in both quantity and diversity (notably Birmingham has been extremely successful in the ERC Starting Grant scheme: of the 17 awarded to UK Mathematicians in the five calls until 2012, 3 were awarded to Birmingham Mathematicians);
- the ability of the School to **recruit and retain first-class researchers** to both open-ended and fixed-term contracts has seen a marked improvement, and is evidenced by the 7 EPSRC First Grants, 1 EPSRC Fellowship, 1 five-year Royal Society URF and 2 EU Career Integration Grants obtained by probationary lecturers in the REF period;
- the School has a much **broader sustainable research base**, providing a more stimulating research environment;
- esteem factors indicate that the School has taken **a more prominent place in the international research community**, with some sub-disciplines operating at the highest level.

What follows is a description of the School's Research Strategy by research group. This was tested in 2012 with an Institutional Review ("VC Review Panel") with external reviewers that endorsed the strategic direction and strong future focus.

Pure Mathematics. In the REF period the broad research strategy of the PMG has been to establish and consolidate world-class research groups in both Analysis and Combinatorics, while strengthening and broadening its existing expertise in Algebra. This vision for the Pure Mathematics group, which is in part, an on-going response to the recommendations of the IRM, was strongly supported by the College, and has resulted in three powerful research subgroups.

Each of the three research subgroups within Pure Mathematics are the product of ambitious, coherent and on-going *scientific strategies*. These are described below.

The *Algebra group* is a cohesive, world-leading *centre for Groups, their Representations and Applications*. Under the leadership of Professors Christopher Parker and Sergey Shpectorov, its ambition in the REF period has been to extend its core activities in group theory, group geometries and Lie theory - which includes applications in computer algebra, geometries emerging from Lie algebras and fusion systems - to include world leading research in representation theory. Success in achieving this may be seen through (i) the appointments of two exceptional researchers working at the interface of representation theory and group theory (Craven and Evseev). Currently Craven (appointed as a Birmingham Fellow) is supported by a 5-year Royal Society URF and Evseev has recently completed his EPSRC postdoctoral fellowship; (ii) new high-profile collaborators, including Guralnick (UCLA), Rouquier (Oxford, UCLA); (iii) major LMS/EPSRC-funded conference organisation, putting the spotlight on the breadth of algebraic excellence at Birmingham.

The vision of the *Analysis group*, led by Professor Jonathan Bennett, has been to establish an internationally-leading *centre for Modern Harmonic Analysis and its Interactions*. Success in achieving this in the REF period may be seen through (i) the appointments to Lectureships of 2 euclidean harmonic analysts (Bez, Reguera – Birmingham Fellow), a geometric measure theorist (Maleva), and 2 specialists in nonlinear dispersive and kinetic PDE (Cañizo, Gutiérrez); (ii) the pivotal role of Birmingham as the hub of the LMS/ERC-funded Harmonic Analysis and PDE Research Network (with nodes currently in Bath, Edinburgh, Warwick and Madrid); (iii) a current portfolio of UK/EU research grants worth approximately £1.3m, funding numerous postdoctoral researchers; (iv) a broad network of international collaborators, including J. Carrillo (ICL), M. Lacey (Georgia Tech.), D. Preiss (WMI), T. Tao (UCLA), L. Vega (Bilbao); (v) a 2011 LMS Whitehead Prize and a 2012 ERC Starting Grant (Bennett).

The vision of the Combinatorics group, led by Professors Daniela Kühn and Deryk Osthus, has been to build an internationally-leading *centre for Extremal and Probabilistic Combinatorics*. The success of the group is demonstrated by the following: (i) the appointment of three new lecturers in 2011 -- N. Fountoulakis (Discrete Probability), D. Hefetz (Random graphs, Combinatorial Games), R. Mycroft (Extremal Combinatorics). In addition, A.Treglown (Extremal Combinatorics) was appointed as a Birmingham Fellow in 2012; (ii) extensive international collaborations, including M. Krivelevich (Tel Aviv), B. Sudakov (ETH/UCLA); (iii) attraction of excellent PhD students from the UK (mostly with distinctions from Cambridge) and abroad; (iv) current grants with a total value of about £1.9m, currently funding 6 research fellows, including two ERC starting grants (Kühn and Osthus); (v) invited lectures at the ICM 2014 (Kühn and Osthus).

The return on investment in these three centres of excellence in the current REF period, both

financially and in terms of international standing, has been unprecedented. **As a result the School and University view their continued growth and consolidation as a strategic priority**.

Applied Mathematics. In response to the findings of RAE 2008, the School has made bold strategic investments predominantly in two main research areas: *Nonlinear Systems* and *Biomathematics*. The purpose of this on-going strategy is to shape a contemporary and outward-facing applied mathematics group, equipped to lead fundamental research at an international level, while establishing impact via collaborative projects with industry and commerce in both the public and private sectors.

The School's underpinning strategy for the *Nonlinear Systems Group*, led by Professors John Leach and David Needham*,* has been to shape a coherent core of both established and talented young researchers with exceptional analytical and computational backgrounds. Success in achieving this is evidenced by (i) a strong base of established members with expertise in a variety of aspects of applied analysis, nonlinear waves in fluids, nonlinear evolution PDE, and industrial engineering mathematical modelling (Leach, Needham, Stephen, Shikhmurzaev, Wang); (ii) the appointments of 4 excellent early career researchers (Bespalov, Nicks, Tzella, Uddin); (iii) the establishment of industrial partnerships with companies such as Rolls Royce, Schlumberger PLC, Statoil AS and Qinetiq, generating income in excess of £200K; (iv) a joint £5.5M EPSRC-funded DTC with the School of Chemical Engineering; (v) current RCUK grants (held within the University and with other institutions) approaching £1M; (vi) the successful hosting of the 2011 BAMC; (vii) the organisation of a variety of LMS and ENSOR Review workshops (inverse problems, reaction-diffusion theory, and bubble dynamics).

The School's developing strategy for the newly-formed *Biomathematics Group,* led by Dr. David Smith*,* has been to appoint a small number of excellent and well-connected early-career researchers who are able to forge close interdisciplinary research partnerships both within the UoB and further afield. This has been brought to fruition through the appointments of 3 dynamic early-career researchers (Dyson, Jabbari – Birmingham Fellow, D. Smith) and the cross-campus Systems Science for Health initiative. This small, yet well-known group is involved in more than £3.5M of competitively-awarded research funding over the REF period from a variety of sources including EPSRC, MRC, BBSRC, STFC and Birmingham Science City, and collaborates widely with world-leading experimental and theoretical groups (including the Universities of Dundee, Nottingham and Oxford, Birmingham Women's hospital, and internationally in Australia, Canada, France, Germany, Mexico, Portugal and the USA).

The Nonlinear Systems and Biomathematics initiatives have been very successful in galvanising research activity within the AMG, driving a significant rise in the quality of research output within the REF period. **The consolidation of these initiatives is a strategic priority** for the AMG in the next assessment period, particularly in relation to the substantial and flourishing industrial/commercial links established since 2008. These activities provide an essential route to impact for the AMG; see the Impact Case Studies for evidence of the considerable success.

Further to this strategy, the AMG strongly supports a successful *Numerical Analysis Group,* which naturally underpins the computational component of the Nonlinear Systems Group. In the REF period the strategy of this group has been to develop a portfolio of industry funding and grow through strengthening links with the Optimisation Group. Recent successes include funding from Boeing, and applications of research output in Aerodynamics, Computational Ecology, Quantitative

Finance, Mathematical Biology and Fuel Cell Dynamics.

Optimisation and Statistics. The main goal of the Optimisation group in the REF period has been *to pioneer the development of theoretical and computational tools for interdisciplinary industrial problems*, with research focusing on two main strategic areas: (a) theory and computation of large-scale nonlinear optimisation, and (b) tropical mathematics and max-algebra. The success of this is evidenced by (i) the group's central involvement in FP6 and FP7 projects led by the aerospace industry; (ii) the group's strategic partnership with the *Numerical Algorithms Group* (NAG), involving the implementation of its software in the celebrated NAG Library; (iii) significant external funding, including several EPSRC grants in both main academic research areas; (iv) the organisation of high-visibility international conferences and workshops in Birmingham, including the establishment of a new biannual IMA-funded international conference series "Optimization and Numerical Linear Algebra" (Birmingham 2007, 2010, 2012), attracting leading international researchers in the field. The School intends to build on this success, and is **committed to the continued development of this outward-facing research strategy.**

Future Strategy for Statistics. In the REF period the School has investigated several different models aimed at creating a contemporary and stable Statistics Group. In partnership with the College of Medical and Dental Sciences (MDS), the School has initiated the establishment a University-wide *Centre for Biostatistics,* which will bring together the significant statistical expertise already within the University. This initiative, which will shift focus from theoretical to more applied statistics, has been successfully trialled during the REF period with the joint Mathematics/MDS appointment of Dr R. Riley. A further joint appointment has already been approved for 2013, and another planned for 2014. This major investment, which also supports the rapidly-developing Biomathematics group, is intended to create a vibrant interdisciplinary statistics school, capable of securing research council and industrial funding, establishing a concrete pathway to impact, and attracting high quality doctoral/postdoctoral researchers.

c. People, including:

i. Staffing strategy and staff development

The staffing strategy of the School of Mathematics within the REF period has, and continues to be, predominantly focussed on appointing gifted early-career international researchers to Lectureships. The purpose of this strategy is to: (i) expand and consolidate both the emerging and already flourishing research groups, in line with the School's Research Strategy; (ii) ensure a stable and committed body of academic staff; (iii) grow and diversify the School's research grant portfolio; (iv) generate a vigorous research environment for staff, postdoctoral researchers and students. This strategy has proved extremely successful; a claim most powerfully evidenced by the 7 EPSRC First Grants, 1 EPSRC Fellowship, 1 five-year Royal Society Fellowship and 2 EU Career Integration Grants *obtained by probationary lecturers alone* in the REF period.

This on-going staffing strategy, which is distinctly international, has aligned closely with that of the wider University. Within the REF period the University has played a pioneering role in the introduction of permanent Lecturer-level *Research Fellowship* positions to the UK academic system. The School has secured 4 *Birmingham Fellows* (Craven, Jabbari, Reguera,Treglown) since 2011. These particularly prestigious positions involve full cross-campus competition, and are intended to identify future research leaders at an early stage. Most notably, Craven has since obtained a 5-year Royal Society Fellowship. In the next assessment period the School plans to continue with this highly successful and time-tested early-career staffing strategy in the scientific areas identified in its Research Strategy.

All staff members are supported scientifically via **a variety of substantial and sustained activities aimed at encouraging research**. In particular, the School provides (i) a regular *Mathematics Colloquium*, with highly distinguished speakers (recent highlights include, J. Conway, B. Green, T. Tao); (ii) formal weekly external-speaker *Seminar Series* in each of Algebra, Analysis, Combinatorics, Applied Mathematics, and Numerical Analysis and Optimisation; (iii) informal weekly *Study Groups* in each of Algebra, Analysis and Combinatorics; (iv) frequent and varied *cross-disciplinary seminars*, involving both external and local speakers. In addition, the School has a strong culture of research networking and conference/workshop organisation. For example, the School is the hub of 3 lively and well-established *LMS/ERC-funded research networks* (Algebra, Analysis, Optimisation), with both UK and EU nodes.

In the REF period the more experienced academic staff members have been supported through (i) periods of Study Leave, particularly for excellent researchers with major administrative loads, or in the interests of equality of opportunity; (ii) performance-related research expenses accounts; (iii) reduced teaching and administrative loads for staff with substantial commitments to externally-funded research projects; (iv) a highly effective promotions process. Each member of staff wishing to apply to the University for promotion (at all levels) is assigned a mentor from within the School. Within the REF period excellent performance has been regularly rewarded in this way (7 Senior Lecturers, 5 Readers, and 5 Professors). After considerable internal consultation, the School has recently approved the appointment of a dedicated and experienced non-academic Admissions Tutor, providing substantial support to academic staff involved in the increasingly demanding admissions process.

An experienced senior member of academic staff oversees the induction of all new lecturers into the School's processes and monitors their progress during the entire 3-year probationary period. In addition, all new lecturers are assigned a research mentor. This mentor is responsible for (i) giving advice on research supervision and activity prioritisation; (ii) encouraging initiatives, such as workshop organisation and new collaborations; (iii) providing on-going feedback on research grant applications; (iv) providing advice with regard to promotions. The research of probationary lecturers is further supported by a considerably reduced teaching load (approximately 50% of the typical load initially), and protection from major administrative roles for the duration of their probation.

Fixed-term Research Fellows are supported by an assigned mentor (typically the PI on an associated grant), who (i) encourages full engagement with the scientific activities of the School; (ii) provides opportunities for teaching UG/PG courses for the purposes of their academic career development (such contributions are not expected); (iii) encourages and finances participation in international conferences and workshops; (iv) collaborates with the Fellow on a research project, while making appropriate provision for academic freedom.

All Academic Staff are required to prepare for and attend an annual *Performance Development Review*. The principal intention of this is to encourage researchers to reflect on their practice and formulate their own individual career development strategies.

Current staff with personal research fellowships: Bennett (ERC Starting Grant); Cañizo (CIG), Craven (5-Year Royal Society URF); Fountoulakis (CIG); Jabbari (MRC Research Fellowship); Kühn (ERC Starting Grant); Osthus (ERC Starting Grant); Piguet (FP7 Marie Curie intra-European Fellowship).

International Staff Appointments in the REF period. The heads of the research subgroups coordinate detailed search committees during periods of recruitment, seeking assistance from their wide networks of international collaborators and contacts, and advertising extensively. A recent Lectureship vacancy in Pure Mathematics attracted over 140 applications, with the great majority international. All international appointments within the REF period have been at Lecturer level and form an important part of this submission. All outgoing international staff members were appointed prior to RAE 2008, with the majority to senior positions. This is evidence of the sustained success of the School's on-going early-career recruitment strategy and staff support structure.

Outgoing (international): Cowling (Australia), Gramlich (Germany), Guha (India), Hundertmark (USA), Johansson (Sweden), Rückmann (Norway), Verbitsky (USA).
Incoming (international): Bespalov (Russia), Cañizo (Spain), Evseev (Russia), Fountoulakis (Greece), Hefetz (Israel), Maleva (Russia), Reguera (Spain), Tzella (Greece).

Equality and Diversity. The School has recently created a *Director of Equality and Diversity*. This experienced member of academic staff is leading the School's take-up of the *Athena-Swan Charter (*the School was awarded a *Bronze Award* in 2013*)*, and chairs a dedicated committee responsible for ensuring that measures are in place to provide practical support for staff with different personal circumstances. This has led to flexible timetabling for staff with young families and for the purposes of religious observance, study-leave support after periods of maternity leave, in addition to other measures such as a private place for breastfeeding. The School supports diversity in recruitment by ensuring that applicant pools are suitably international, and selection committees are gender-balanced. In particular, 4 of the last 8 academic appointments in the School have been women, with a similar proportion among doctoral students in 2013. Similar equality of opportunity measures apply in the context of promotions. Furthermore, all staff members are expected to complete a University-led equality and diversity training session.

In addition to the School's Athena activities, in December 2012 female academic staff members were encouraged to attend a series of College focus groups with the aim of identifying barriers to career progression. This has led to the establishment of a College-level Academic Women's Network, offering personal and professional development activities, such as promotions workshops. All female members of staff in Mathematics are regularly encouraged to attend these network sessions.

ii. Research students

School and EPSRC-supported students enter with four year undergraduate degrees with first class marks. The offer for 2012 and 2013 entries was a first class MSci degree with an average mark exceeding 80% (rising from 70% over the REF period) or a distinction in Part III. The quality of students has been exceptionally high (e.g. IMO Silver Medallist F. Knox).

Training and Support. The School regulations for PhD students require that they pass at least 100 lecture hours of postgraduate level training in Mathematics. These courses are provided through MAGIC, APTS and NATCOR consortia or from its own graduate level courses. In addition to these formal components, the School provides **an extensive range of scientific activities aimed at encouraging students to engage with research communities at all levels**; locally, nationally and internationally. There are 5 long-running weekly *Seminars series*, a regular *colloquium*, and internal *Study Groups* in the majority of the main sub-disciplines. Often these study groups bring together disparate parts of the School; recent examples of joint study groups

include “Dispersive PDE”, “Random Walks in Groups” and “Additive Combinatorics”, involving the Algebra, Analysis, Combinatorics and Nonlinear Systems groups. Students are also exposed to the external research community through the numerous LMS/ERC/EPSRC-funded conferences and research networks run by the School. The School has also taken good advantage of the LMS/EPSRC funding for *Summer Schools*, running the courses “Algebraic groups and related topics” and “Random Graphs, Geometry and Structure” in the REF period. One of the highlights of the training provision is the student-run *PG Colloquium*, which in 2012 alone held 9 events with distinguished external speakers. The research students are further supported by a *Welfare Team* and the *School Careers Officer*, as well as having designated academic supervisors and co-supervisors. Progress is monitored by supervisors meeting their students normally once per week. There is an annual process for progression, including the submission of an MRes thesis (equivalent) by the end of Year 2.

Continuing support. The School of Mathematics has been successful with applications to the University for *PhD Plus/PhD prize* positions, having secured 5 since 2010. Researchers supported in this way have since obtained positions at the Heilbronn Institute (Barwell), Oxford (McInroy) and Birmingham (Meyer, Treglown).

d. Income, infrastructure and facilities

Income. The School has been increasingly successful in attracting external research funding. Since 2008 the School as a whole has been awarded external research funding of over £6m (compared with £1.6m in the previous assessment period). For instance, there have been 5 successful EPSRC First Grant applications by new lecturers *since 2012 alone*. To provide additional support (for early career researchers in particular), and **ensure the sustainability** of this trajectory, the School has recently established the position of a *Grants Director* (with two deputies), whose role is to give well-informed advice on proposals and funding. Moreover, there are regular workshops on funding opportunities run by the School, the College, as well as centrally by Research and Innovation Services.

In Pure Mathematics, the Algebra group has two members with personal research fellowships, including a 5-year Royal Society URF. The Analysis group has recently been awarded 2 EPSRC First Grants, 3 FP7 grants and an ERC Starting Grant. The Combinatorics group holds 2 FP7 grants, 2 EPSRC First Grants and a Standard Grant, as well as 2 ERC Starting Grants. Most notably, of the 17 ERC Starting Grants awarded to UK Mathematicians in the five calls until 2012, 3 were awarded to Birmingham Mathematicians.

In Applied Mathematics, the Nonlinear Systems and Numerical Analysis groups hold major EPSRC funding in partnership with the University of Nottingham, an EPSRC-funded DTC (with the School of Chemical Engineering at Birmingham), along with a substantial portfolio of industrial/commercial funding (including BAA, Boeing, Kodak, Rolls Royce, Schlumberger PLC, Statoil AS, Qinetiq and Yorkshire Water). The Biomathematics group currently holds an EPSRC First Grant, an MRC Fellowship, forms part of a £2.1M MRC Challenge Grant (joint with Cancer Sciences), and holds a major BBSRC grant with the Centre for Plant Integrative Biology at the University of Nottingham.

The Optimisation and Statistics group is currently supported by two major EPSRC grants (both in Optimisation). Moreover, it has strong industry links and funding, including Airbus, Hewlett Packard and NAG.

The School is focussed on sustaining its recent success in attracting grant income. As the overall EPSRC budget is likely to decrease, the School intends to become less reliant on this by further

diversifying its research income. In particular, one aim is to further increase income from FP7 (and subsequently Horizon 2020). Opportunities in this area frequently involve substantial international networks and collaborations. Hence it is important for the research groups to extend and consolidate their external links, with a view to applying for relevant calls.

Infrastructure and facilities. The School of Mathematics resides in the Watson Building, at the heart of the campus. On site it has a large lecture room equipped with (EPSRC-funded) state-of-the-art multi-institution video-conferencing facilities, which are used heavily for doctoral training via the MAGIC consortium. The Watson building houses several modern lecture theatres, with the largest having a capacity 160, allowing seminars, colloquia, workshops, conferences and receptions to be held on site. The School has a rolling investment programme which in 2013 has seen significant refurbishment and 25 new PCs. All staff and research students have access to standard mathematical tools such as Maple, Mathematica and MatLab on their office computers. In addition, the School benefits from full access to BEAR: the Birmingham Environment for Academic Research. BEAR is a cluster which consists of 848 core processors capable of a peak performance of 15 TFlops.

Outside of the Watson Building, the School has developed a number of partnerships across the campus. The *Systems Science for Health* initiative, which is a key facility for the Biomathematics group, provides the focus for interdisciplinary research between the School and the Colleges of Life and Environmental Sciences and Medical and Dental Sciences. The £5.5m EPSRC-funded DTC in *Hydrogen Energy, Fuel Cells and their Applications* provides a long-term platform for collaborative research with the School of Chemical Engineering.

The proposed *Centre for Biostatistics* represents the largest infrastructural investment plan for the next assessment period, with up to two academic appointments already approved for 2013/14.

e. Collaboration or contribution to the discipline or research base

Research collaborations. Each research subgroup within the School has an extensive portfolio of national and international research collaborations, with many providing fundamental and highly influential contributions to the research base within the REF period. As may be seen from the Impact Case Studies, this has had a significant impact in the wider industrial and commercial economy. These collaborations have been supported financially by numerous external grants, the School Seminar Series and School/College research accounts. **The following major exemplars have played an important role in shaping the research strategy of the School**, as described in Part (b):

Exemplar 1 (Combinatorics). Project: “Embedding substructures: robustness and quasi-randomness”. Collaborators include Hefetz, Kühn, Mycroft, Osthus, M. Krivelevich (Tel Aviv), B. Sudakov (UCLA/ETH Zurich), T. Szabó (FU Berlin). The collaborators have pioneered probabilistic techniques, leading to the proof of several conjectures which had been open for decades (e.g. Kelly’s Conjecture, Summer’s Universal Tournament Conjecture, the 1-Factorization Conjecture). This progress has opened up new avenues of related research, in particular on the resilience and robustness of combinatorial properties as well as combinatorial games. This on-going research, which will be presented in an invited ICM2014 lecture (Kühn and Osthus), is supported by the EPSRC (Hefetz) and two ERC Starting Grants (Kühn 2010, Osthus 2012).

Exemplar 2 (Algebra). Project: “Representations of groups and algebras”. Collaborators include Craven, Evseev, Goodwin, Magaard, Brundan (Oregon), Guralnick (USC), Hiss (Aachen), Kleschev (Oregon), Rouquier (UCLA), Testerman (EPFL). The research has made significant

contributions to Brauer's conjectures in modular representation theory, to the maximal subgroup problem in finite groups, to the Higman PORC conjectures, to representations of W-Algebras. Significant progress has been achieved and new directions of research established. This multi-national research has been supported by an EPSRC fellowship (Evseev), EPSRC first grant (Goodwin) and since 2012 by Craven's Royal Society URF.

Exemplar 3 (Analysis). Project: "Transversal Multilinear Harmonic Analysis". Collaborators include Bennett, Bez, Gutiérrez, Carbery (Edinburgh), Lee (Seoul), Rogers (Madrid), Tao (UCLA). The results of this long-term and on-going project, combined with 2011-13 work of J. Bourgain and others, have led to dramatic progress on longstanding problems across mathematics, such as the celebrated Fourier Restriction Conjecture. This work and influence is cited by the LMS Whitehead Prize Committee 2011, forms the focus of Bennett's 2012 ERC Starting Grant, and is further funded by the 2012 EPSRC grants of Bez and Gutierrez.

Support for and exemplars of interdisciplinary research. The School has developed a wide variety of interdisciplinary research projects, which are detailed in the Impact Document. Since RAE 2008, the School has forged or developed industrially-funded partnerships with StatOil, Schlumberger, Birmingham Women's Hospital, Airbus, Boeing, Malvern Instruments, NAU, the ESA, and Astrium. The School has also benefited considerably from interdisciplinary collaborations with academic departments, both in Birmingham and externally. The School and University view such activity as central to its operations, as may be seen by the explicitly cross-disciplinary aspects of the 2011-13 *Birmingham Fellows Schemes*.

Exemplar (Biomathematics): Project: "Mechanics in sperm motility". Partners: Birmingham Women's Hospital and the QE Medical School. This major project has drawn considerable attention to the importance of mechanics in sperm motility, and in particular, viscosity and confined geometry effects. The findings have been presented at the internationally-leading Gordon Conference on Reproduction and Activation of Development, in addition to others in China and the EU, and an invited review in Molecular Human Reproduction.

User-led research activities/strategies. The School's new Biomathematics group is currently the most comprehensive user-led research group. This is manifest from its conception as an interface for the School with the Life, Environmental and Medical Sciences, its day-to-day cross-campus/institution activities, and its collaborative funding successes. A second major example is the £5.5m EPSRC-funded DTC in *Hydrogen Energy, Fuel Cells and their Applications,* which has aligned School research strategies with national EPSRC and government funding priorities. Looking forward, the School's proposed Centre for Biostatistics is in part a response to a growing external prioritisation of research in Applied Statistics.

The following paragraphs provide **exemplars of leadership in the academic community**:

***Prestigious invitations*.** The international standing and influence of the members of the School is reflected in the regular and sustained (accepted**)** invitations to prestigious international research institutes since 2008, including *AIM-Palo Alto* (Butkovic, Magaard); *BCAM-Bilbao* (Gutiérrez); *BIRS-Banff* (Cañizo, Craven, Fountoulakis, Hefetz, Kühn, Magaard, Osthus, Parker); *CIRM-Luminy* (Craven, Goodwin, Kocvara, Maleva); *CRM-Barcelona* (Bennett); *CRM-Pisa* (Bennett, Bez, Gutiérrez); *CRM–Montreal* (Fountoulakis); *CSIC-Madrid* (Bennett, Bez); *Hausdorff Institute* (Bennett); *IMA-Minnesota* (Tzella); *Indian Statistical Institute* (Cañizo, Magaard); *IAS-Princeton*

(Hoffman); *IPAM-Los Angeles* (Bennett, Kocvara, Maleva); *ICMS-Edinburgh* (Bennett, Bez, Cañizo, Kuhn, Magaard, Mycroft, Needham, Osthus, Treglown) ; *INI-Cambridge* (Bennett, Cañizo, Goodwin, Gutiérrez , Kocvara, Mycroft); *MBI-Ohio* (Dyson); *MSRI-Berkeley* (Cañizo, Craven, Fountoulakis, Maleva); *MFO-Oberwolfach* (Bennett, Cañizo, Craven, Evseev, Flavell, Goodwin, Hefetz, Kühn, Magaard, Osthus, Parker, Shpectorov); *Mittag Leffler Institute* (Kühn, Osthus); *RIMS-Kyoto* (Bez, Goodwin); *Sobolev Institute* (Parker); *Von Karman Institute* (Stephen).

High-profile invited talks. Notable recent invitations include "ICM 2014" (Kühn, Osthus), "2014 SIAM Conference on Discrete Mathematics" (Kühn, plenary speaker), "South African Mathematical Society Congress 2013" (Magaard, keynote address), "EUROCOMB 2011" (Kühn, plenary speaker), "Discrete Harmonic Analysis" at the INI (Bennett, 2011), "Groups 2012" (Flavell), the "Erdos Centennial Conference" (Osthus, 2013), "Extremal Combinatorics" at UCLA (Hefetz, 2013), "Polynomial Optimisation" at the INI (Kocvara, 2013).

Editorial board membership. The School contains board members for numerous international journals. Current highlights include: The Bulletin, Journal, Proceedings and Transactions of the LMS (Bennett); SIAM J. Optimization (Kocvara); Combinatorica (Kühn); Discrete Mathematics (Osthus); Journal of Group Theory (Parker, Managing Editor); Q. Journal of Mechanics and Applied Mathematics (Needham); IMA Journal of Applied Mathematics (Needham, Managing Editor).

***Fellowships/Awards/Prizes*.** The School hosts a number of prestigious UK and EU fellowships; see Section (c). In particular, it has been one of the most successful School in the UK in obtaining *ERC Starting Grants* (Bennett 2012, Kühn 2010, Osthus 2012), and has a 5-year Royal Society URF (Craven 2012). The School also received a London Mathematical Society *Whitehead Prize* in 2011 (Bennett), "for foundational contributions to multilinear geometric and harmonic analysis".

Programme Committee membership. Members of the School have chaired or co-chaired numerous major national and international conferences, locally, nationally and internationally, since RAE 2008. Examples of important School-hosted events are the BAMC 2011 (Needham, Chair); the LMS Midlands Regional Meetings in both 2008 and 2011, with subsequent international conferences "Harmonic Analysis and PDE" (Bennett, Chair) and "Representation Theory in Modern Mathematics" (Goodwin, Chair). Other high-profile conferences held at Birmingham include the EPSRC-funded "Probabilistic Methods in Graph Theory" (Kühn, Mycroft, Osthus 2012), "Banach Spaces" (Maleva 2012), and the LMS/IMA-funded "Mathematical challenges in bubbles and biological fluid mechanics" (D. Smith 2013). Externally, examples include "Degenerate Reaction-Diffusion Systems" (Needham 2009), "BMC 2011" (Bennett, co-Chair of session "Harmonic Analysis"), the "UK-India Workshop in Industrial and Applied Mathematics 2011" (Uddin); the "SIAM Symposium on Discrete Algorithms 2012" (Kühn), "EUROCOMB 2013" (Kühn), "RANDOM 2013" (MSRI, Fountoulakis), "Positional Games" (MFO, Hefetz)," 2014 SIAM Conference on Discrete Mathematics" (Osthus, Chair of session "Extremal Graph Theory"). The School also chairs 3 longstanding UK/EU Research Networks, each holding 3 workshops annually (Bennett, Butkovic, Parker).

***Panels/committees (selected)*.** Royal Society International Fellowships Panel (Parker); Assessment Panel for EPSRC Mathematics of Life Sandpit (Needham); EPSRC Mathematics Prioritisation Panel (Zhao); Italian National Agency for the Evaluation of Universities and Research (Cañizo); NC3Rs funding panel on Mathematical Modelling in Toxicology (D. Smith).