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APPENDICES

Please note that the following statistical information may be obtained from the Institute on request, or from **http://www.newton.cam.ac.uk/reports/0304/appendices.html**

1 Long-Stay Participants
2 Chart of Visits of Long-Stay Participants
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Director's Foreword

This Annual Report records another year of achievement and progress for the Newton Institute, confirming the wisdom of its founding fathers in establishing the pattern of concentrated research programmes of up to six months duration, with participants chosen from the best mathematical scientists from all over the world. That is not just my opinion, but the considered verdict of peer review by our funders in the UK and in Europe. It is essential to maintain that scientific quality if we are to continue to attract both visitors and adequate resources, and the signs are that we can do this.

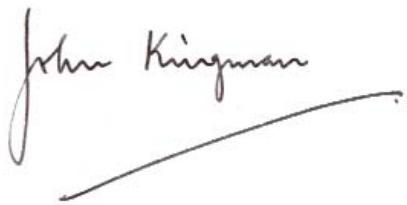
This confidence is due in part to the strong pipeline of future programmes. At the time of writing we are already beginning to see an excellent series of programmes extending into 2007, but I would like to emphasise how much we welcome new ideas and innovative proposals. If you the reader are motivated by reading this Report to come forward with suggestions, I shall be delighted.

The Institute exists not only to contribute to the advance of the mathematical sciences for their own sake, but specifically to serve and enrich the UK mathematical community. As I go around the country (see page 10), or talk to our correspondents in universities (page 7), I see the value of bringing the best mathematicians to the UK. But the universities must play their part by taking advantage of the presence of our visitors, whether by coming to workshops in Cambridge or by inviting our participants to give seminars in their own departments (see page 9).

Mathematics today has a higher profile in public discussion, and we are as a nation at last realising how important it is to get young people excited about a subject which underlies all modern science and technology. The sort of cutting edge research that takes place at the Newton Institute adds to the appeal of mathematics, and we work with such activities as the Millennium Mathematics Project to try to break the vicious circle which has so long blighted school mathematics. Young people who get interested in mathematics at school will become the teachers of the future, and will communicate their enthusiasm to the next generation, and so on by induction.

The success of the Newton Institute depends of course on the willingness of busy and distinguished scientists from other countries to disrupt their home lives to spend time in Cambridge, and it is vital that we offer them an environment in which they can work and collaborate effectively. We are extremely fortunate to have a building so well designed for the purpose, but we are also blessed with support staff who are so devoted to the welfare of our visitors. This is my annual opportunity publicly to record my thanks to them for all they do, which I know is greatly appreciated by the visiting scientists who are the lifeblood of the Institute.

While it is invidious to single out individuals, I must make an exception in the case of Wendy Abbott, who has retired after working at the Institute almost since its foundation. Latterly she has been the Assistant to the Director, and both Keith Moffatt and I relied on her wisdom and experience. Her cheerful efficiency will be much missed by us all.



31 July 2004

Brief Scientific Report on Programmes

For full scientific reports see pages 20 to 48.

Programme 52: Spaces of Kleinian Groups and Hyperbolic 3-Manifolds

The modern subject of Kleinian groups and hyperbolic 3-manifolds divides roughly into three phases: the Ahlfors–Bers school (before about 1980), the Thurston era (1980–95), and post-Thurston. Thurston's ideas revolutionised the field. After more than a decade of turmoil spent debating and consolidating his insights, by the mid-'90s we appeared to have settled down on a number of hard problems which still seemed pretty far out of reach. The last two or three years, however, have seen a series of profound and far reaching breakthroughs, with new results and techniques appearing almost monthly, to the point where many of these old problems are now close to resolution.

This meeting turned out to be the international gathering at which this plethora of new results was disseminated to a wider audience for the first time. The programme was especially concerned with the classification and location of discrete groups in the ambient space of all representations from the fundamental group of some fixed 3-manifold into $SL(2,\mathbb{C})$. Three major problems were open when the meeting was first planned: Marden's Tameness Conjecture, the Bers Density Conjecture and Thurston's Ending Lamination Conjecture. All three have since been proved.

A somewhat novel feature was that one day was devoted mainly to experimental computer graphics, including the first ever picture of 3-dimensional slices of the discreteness locus in a 4-dimensional parameter space, made using software developed for medical imaging.

Programme 53: Interaction and Growth in Complex Stochastic Systems

Random growth processes play an increasingly important role in various parts of pure and applied mathematics, with applications in many areas of natural science, engineering, humanities and medicine. Traditionally, growth processes were studied in many disciplines in a rather isolated fashion which can be explained by a broad variety of models and phenomena. However, major recent advances have fundamentally changed our perceptions of well established problems, and these have tended to unify the area. The aim of this programme was to put together, in a more systematic way, the various strands which have been discovered and studied over the last 10 years, with the main focus on the probabilistic study of random growth processes emerging in theoretical and mathematical physics.

Random processes are often understood by means of an asymptotic limit in which the number of basic random components becomes large. Classical examples usually apply in contexts where the interaction between typical random components becomes negligible in the limit. However, there are many extremely important physical models where such an asymptotic decorrelation does not hold. Such models correspond to a critical behaviour where interaction is strong and statistical scaling properties are highly nontrivial. Examples of contexts in which these models may arise include random walks in a random environment and interactive random walks, interfaces in growth models and equilibrium statistical mechanics, coagulation and fragmentation processes, conformally invariant scaling limits and random matrices. Of particular importance is a connection with conformal field theory.

Programme 54: Granular and Particle-Laden Flows

This programme was devoted to improving the understanding and mathematical modelling of granular and particle-laden fluid systems as they arise in nature, in the laboratory and in industry. Geophysical examples of granular and particle-laden flows include rock avalanches, debris flows, mud flows and turbulent boundary layers with suspended particles, such as volcanic ash flows, underwater turbidity currents and powder snow avalanches. Industrial examples include flows of cereals, pharmaceuticals, alumina, coal and

concrete, in storage facilities, production lines, power stations and construction sites. An objective of the programme was to develop synergies between the various mathematical approaches: the time was felt to be ripe for a concerted effort among mathematicians, physicists and engineers to focus on the fundamental mechanisms responsible for the observed phenomena and to attempt to unify the seemingly disparate models.

Although the topics that were treated in the workshops and the focus days were diverse, the research programme evolved in a way that led it to concentrate onto a relatively small number of rather clearly defined areas. These were: development of theories for rigid and nearly rigid particles and for dense, dry frictional flows; behaviour of the depth-averaged equations for granular avalanches; description of particle size segregation; modelling of pore pressure in fluid–particle systems; mathematical aspects of soil plasticity theories; and the application of kinetic theory to particle-laden flows.

Programme 55: Statistical Mechanics of Molecular and Cellular Biological Systems

We are currently witnessing a remarkable period of renewed collaboration between physicists, mathematicians and biologists. This programme arose from the very promising creative tension between the "randomness" of statistical physics and the "specialness" of biology. Quantum field theory has generated important theoretical tools for studying non-equilibrium and self-organised states, and made contact with increasingly sophisticated experimental data. In biology, it is largely the explosion of accessible data at the level of individual biological molecules and cellular processes that create a ripe moment to provide a context for the two communities to work together. However, the very deep methodological differences between physics and biology constitute severe challenges.

The programme was shaped by a series of four themes that built in logical complexity:

- Single Molecule Biophysics
- Molecular Motors
- Membranes
- Statistical Mechanical Aspects of Gene Signalling

The programme's central aim was to start radically new approaches to research across biology, mathematics and physics in these themes. A successful outcome from such a goal will be very long-term by its nature, but there were several real achievements made during the six months and there are already signs that the new research collaborations begun are yielding fruit.

Programme 56: Random Matrix Approaches in Number Theory

The connection between random matrix theory and the Riemann zeta function was established in 1973 when Montgomery, who had conjectured the 2-point correlations of the Riemann zeros, and Dyson, who was interested in similar statistics of the eigenvalues of ensembles of unitary matrices, realized that the formulae they had discovered independently were in fact identical in a natural asymptotic limit. This programme was designed to draw on the expertise of number theorists, probabilists and physicists to further the recent successes of random matrix theory in predicting results about the Riemann zeta function and other L-functions, thus pointing the way to answering long-standing questions in number theory.

The programme has resulted in the formulation of precise and far reaching conjectures about the behaviour of zeta functions and families of zeta functions in terms of their associated (random) matrix symmetry type. These conjectures now have a firm numerical and theoretical basis. Moreover the techniques, developed in part during the programme, to establish some of these conjectures rigorously have proven to be very useful in establishing subconvexity and density theorems for such families of zeta functions. (The latter are often decisive in applications to classical number theoretic and quantum chaos problems.)

Programme Participation

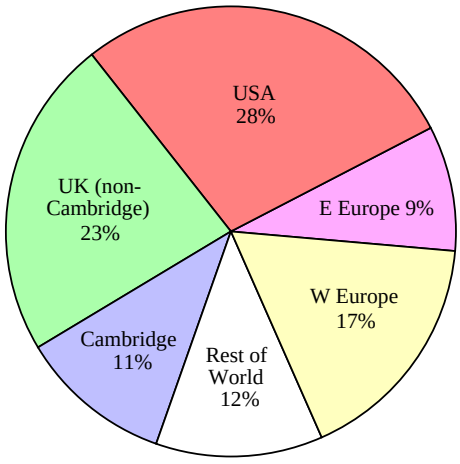
A total of 1333 visitors was recorded for 2003/04. This includes 272 long-stay participants, each staying between two weeks and six months (just under 9 weeks on average), and 277 short-stay participants who stayed for two weeks or less. Within the five completed programmes there was a total of 25 workshops (periods of intense activity on specialised topics) which attracted a further 491 visitors (i.e., those who were not already attending the programme as a long-stay or short-stay participant). An additional 293 visitors attended informally at lectures, workshops, Institute Seminars or other events. Within all the programmes, workshops and other activities, around 986 seminars were given in total at the Institute during the year.

In addition to workshops, which serve to widen UK participation in programmes, programme organisers are encouraged to arrange less formal special days, short meetings or intensive lecture series that can attract daily or short-term visitors, so further opening the activities of the Institute to the UK mathematical community.

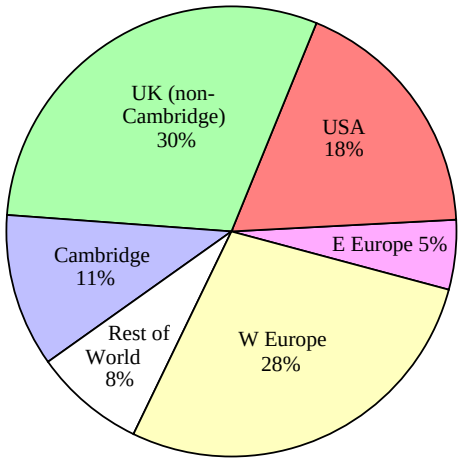
The Institute also funds visits by overseas programme participants to other UK institutions to give seminars (see page 9), and 151 such seminars took place last year.

Programme	Long-stay participants	Mean stay (days)	Short-stay participants	Mean stay (days)
Spaces of Kleinian Groups and Hyperbolic 3-Manifolds	36	21	36	10
Interaction and Growth in Complex Stochastic Systems	77	54	60	9
Granular and Particle-Laden Flows	42	53	56	8
Statistical Mechanics of Molecular and Cellular Biological Systems	62	92	78	7
Random Matrix Approaches in Number Theory	55	63	47	8
Totals	**272**	**60**	**277**	**8**

The pie charts below show the percentages of long-stay and short-stay/workshop participants broken down by country of residence:

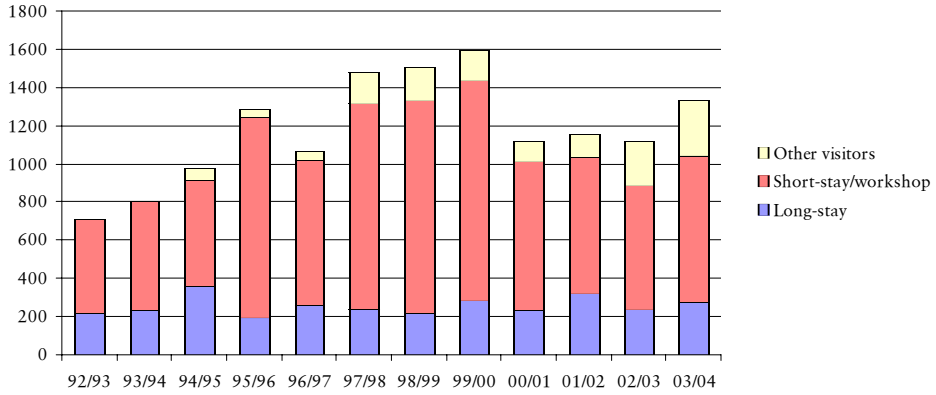


Long-stay participants

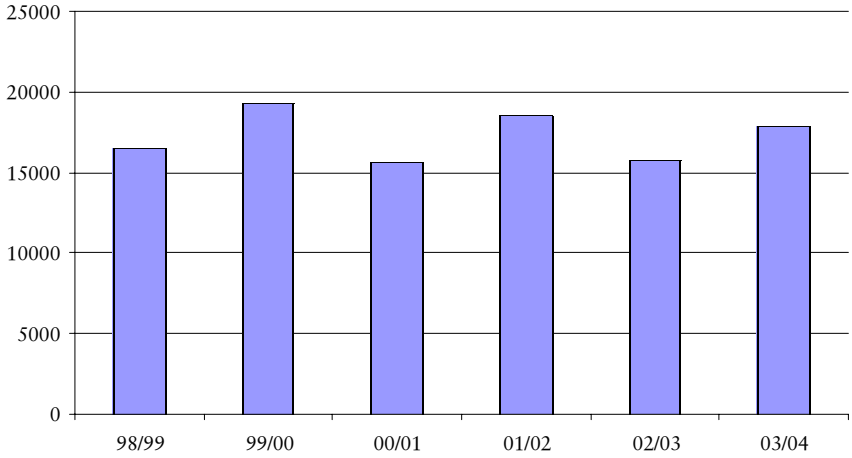


Short-stay and workshop participants

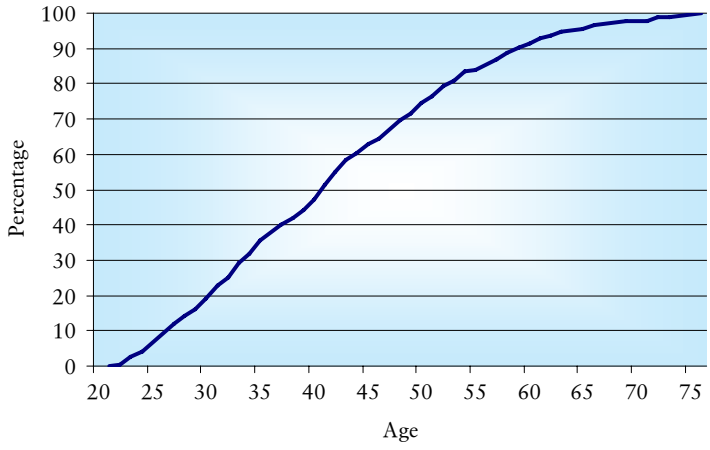
The following chart summarises the total participation figures since the Institute began:



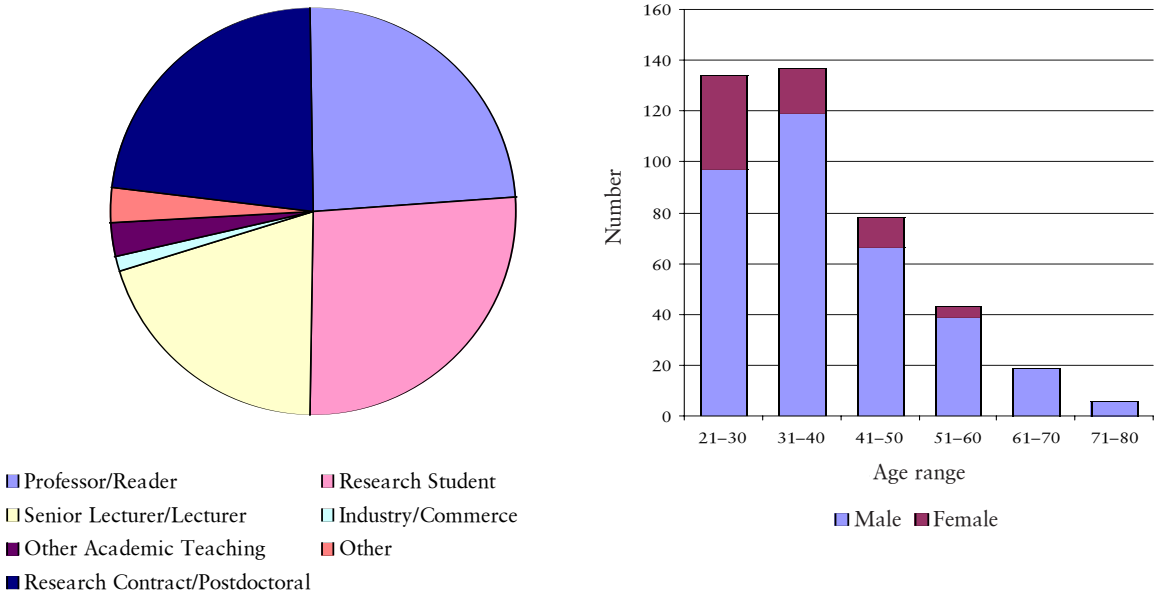
The following summarises the total number of person-days for long- and short-stay participants combined, excluding workshop participants:



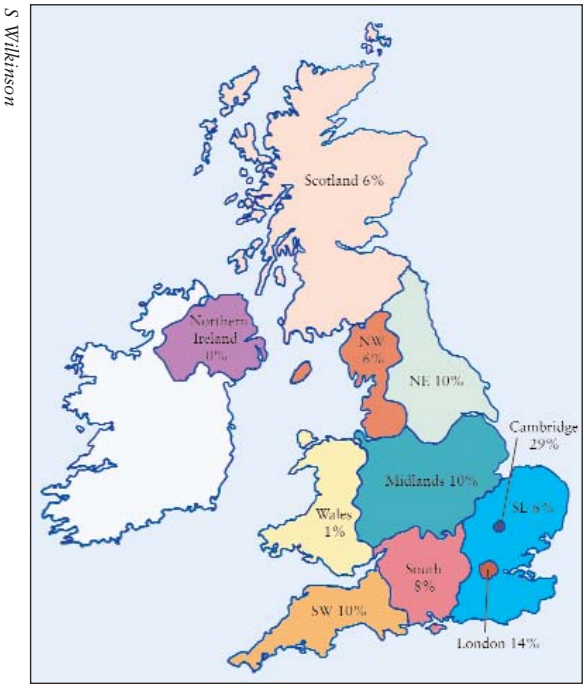
The median age for long- and short-stay participants combined in 2003/04 was 41 years, with an interquartile range of 32–51 years. The following chart shows the cumulative frequency of participant ages:



The academic status, age range and gender balance of only those long-stay, short-stay and workshop participants who visited from **UK** institutions in 2003/04 is illustrated below:



The following map indicates the geographical distribution of long-stay, short-stay and workshop participants from UK institutions during 2003/04:



More detailed statistics, including visit dates and home institutions of participants, and a complete list of seminars and papers are given in the Appendices, available separately from the Institute or at

http://www.newton.cam.ac.uk/reports/0304/appendices.html

Newton Institute Correspondents

Newton Institute Correspondents act as a channel of communication between the Institute and the UK mathematical sciences community (see page 9). Universities and other relevant bodies not yet represented on these lists are encouraged to provide a suitable nominee.

Aberdeen	Dr MS Weiss
Anglia Polytechnic	Dr P O'Donnell
Bath	Dr JF Toland
Birmingham	Dr IV Lerner
Brighton	Prof SW Ellacott
Bristol	Dr F Mezzadri
Brunel	Prof JR Whiteman
Cambridge	Dr C Teleman
City	Dr O Kerr
Dundee	Prof TNT Goodman
Durham	Prof WJ Zakrzewski
East Anglia	Prof G Everest
Edinburgh	Dr A Olde Daalhuis
Essex	Prof PM Higgins
Exeter	Prof AM Soward
Glasgow	Dr C Athorne
Heriot-Watt	Dr S Foss
Hull	Dr Z Brzezniak
Imperial College London	Prof JD Gibbon
Keele	Dr JJ Healey
Kent	Prof PA Clarkson
King's College London	Dr A Recknagel
Lancaster	Dr S Power
Leeds	Prof BD Sleeman
Leeds Metropolitan	Dr E Guest
Leicester	Dr F Neumann
Liverpool	Prof PJ Giblin
Liverpool John Moores	Prof PJG Lisboa
London School of Economics	Prof SR Alpern
Loughborough	Prof AP Veselov
Manchester	Prof AJ McKane
Napier	Prof T Muneer
Newcastle	Dr J Stoyanov
Nottingham	Dr Y Mao
Open University	Prof D Brannan
Oxford	Dr J Norbury
Plymouth	Dr C Christopher
Portsmouth	Prof R Maartens
Queen Mary	Prof PJ Cameron
Queen's	Dr TBM McMaster
Reading	Dr SE Belcher
Royal Holloway	Dr CS Elsholtz
St Andrews	Prof KJ Falconer
Salford	Prof RD Baker
Sheffield	Prof JPC Greenlees
Southampton	Dr CJ Howls
Staffordshire	Prof BL Burrows
Stirling	Prof P Rowlinson
Strathclyde	Prof M Ainsworth
Surrey	Dr PE Hydon
UMIST (Mathematics)	Prof T Subba Rao
UMIST (Physics)	Dr NR Walet
University College London	Prof ER Johnson
West of England	Dr K Henderson
Wales (Aberystwyth)	Prof AR Davies
Wales (Cardiff)	Dr KM Schmidt
Wales (Swansea)	Prof A Truman
Warwick	Dr C Baesens
York	Prof EF Corrigan

Association of Teachers of Mathematics	Dr P Andrews
British Computer Society	Dr M Rodd
Edinburgh Mathematical Society	Prof TH Lenagan
EPSRC	Dr C Batchelor
ICMS	Prof J Toland
Institute of Actuaries	Dr EM Goodwin
IMA (Academic)	Prof D Abrahams
IMA (Organisational)	Mr D Youdon
Institute of Physics	Dr N Walet
LMS	Mr P Cooper
Met Office	Dr MJP Cullen
Mathematical Association	Mr RH Barbour
OR Society	Mr R Hibbs
Proudman Oceanographic Laboratory	Prof PJM Huthnance
Rothamsted Research	Dr M Semenov
Royal Academy of Engineering	Prof J McWhirter
Royal Society	Prof J Enderby
Rutherford Appleton Laboratory	Prof I Duff
Smith Institute	Dr H Tewkesbury

National Advisory Board and UK Mathematics

Membership of the National Advisory Board as at 31 July 2004 was as follows:

Professor Sir Michael Berry FRS	University of Bristol
Professor J Brindley	University of Leeds
Professor KA Brown FRSE	University of Glasgow
Professor P Grindrod	Lawson Software, Oxford
Professor J Howie FRSE	Heriot-Watt University
Dr RE Hunt	Deputy Director, Newton Institute
Professor Sir John Kingman FRS	Director, Newton Institute
Professor PV Landshoff	University of Cambridge
Professor JG McWhirter FRS FREng	QinetiQ
Dr H Ockenden	University of Oxford
Professor EG Rees FRSE	University of Edinburgh
Professor AFM Smith FRS (Chairman)	Queen Mary, University of London
Professor DM Titterington FRSE	University of Glasgow

National Advisory Board

Following discussions with EPSRC, a National Advisory Board (NAB) for the Institute was established during 1999. Its remit is "to advise the Director in all matters relating to the role of the Newton Institute as a National Institute for the Mathematical Sciences."

The membership, as at 31 July 2004, is given in the table above. The overlap with the Scientific Steering Committee and Management Committee is deliberate and intended to ensure good communication with the Board. Some of the issues addressed by the NAB have been:

- The attendance of young UK scientists and training opportunities
- The Institute's strategy vis-à-vis its national role, interdisciplinarity and outreach
- Flexibility in the scientific programming to respond to new developments
- The interests of the EPSRC programmes which contribute to the Institute
- A focus on the Institute's databases to enable it to produce fuller information on participants
- The Institute's mode of interface with industry
- Participation in Institute programmes from different geographical areas of the UK
- Satellite workshops

Professor AFM Smith FRS

- Interface with the International Centre for Mathematical Sciences

Anyone with views about the national role of the Institute is invited to make these known to any member of the NAB.

Symposia Activities

The Institute continues to maintain a list of forthcoming UK symposia, workshops, etc., in the Mathematical Sciences. This list is maintained in consultation with representatives of LMS, IMA, RSS, ICMS (Edinburgh) and the Warwick Mathematics Research Centre. For details, see

http://www.newton.cam.ac.uk/symposia.html

UK Correspondents

During 2000/01, at the suggestion of the National Advisory Board, the Newton Institute established a list of correspondents in UK Universities to act as a channel of communication between the Institute and the mathematical sciences community in the UK. During 2002/03, following further suggestions, the Director wrote to a number of relevant *non*-University institutions and learned societies to invite them also to nominate correspondents. All correspondents are regularly informed about activities of the Institute, and it is their responsibility to ensure that the information is disseminated to relevant groups and individuals within their institution, in both mathematics and other appropriate departments. Correspondents also provide feedback to the Institute. The names of all the correspondents so far established can be found on page 7.

Seminars

Long-term participants in Newton Institute programmes are strongly encouraged to visit other UK institutions during their stay at the Institute, and many did so during 2003/04 (see page 4). To promote this activity, the Institute covers on request the travel costs within the UK for any overseas participant.

The Institute has set up a register of overseas participants who are willing to travel to other UK institutions to give seminars. It is hoped that organisers of seminar series will consult this register when planning their schedule of speakers and will contact potential speakers directly. The register can be found at

http://www.newton.cam.ac.uk/programmes/Speakers.html

Satellite Workshops

The Institute encourages organisers of 4- or 6-month programmes to cooperate with local organisers in holding "satellite" workshops at UK Universities and institutions outside Cambridge.

Satellite workshops are on themes related to the Institute programmes, and involve a significant number of longer-term overseas participants from the Institute. They also, crucially, draw in and involve UK mathematicians and scientists who might not otherwise be able to participate substantially in the Institute programme.

Costs for satellite workshops are typically approximately £10,000 (excluding the overseas travel costs of Institute participants) and are shared approximately evenly between the Institute and the host institution. Both EPSRC and LMS welcome applications from host institutions for grants to cover their share of the costs (subject to the usual review procedures), and we are very grateful to both organisations for the fact that all such applications have so far been successful.

Institutions interested in holding satellite workshops should contact either the organisers of the relevant programme or the Deputy Director, Dr RE Hunt (R.E.Hunt@newton.cam.ac.uk).

Institute Seminars

The regular series of Institute Seminars, held on Mondays during term-time, is intended to be of general interest and to attract a wide range of mathematical scientists. Audio files of Institute Seminars, with accompanying transparencies and stills, are published on the web at

http://www.newton.cam.ac.uk/webseminars/

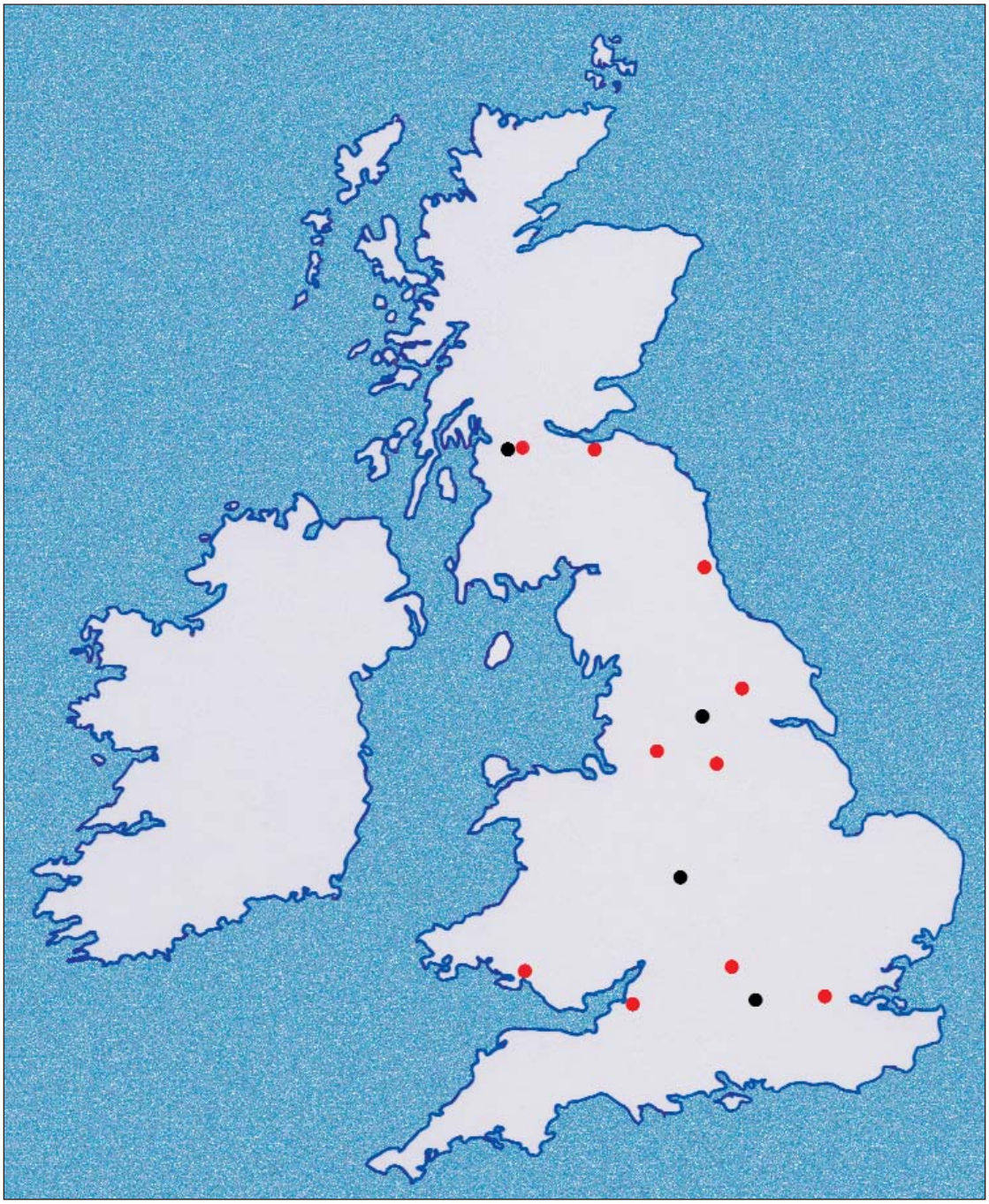
This year's seminars were given by the four Rothschild Visiting Professors:

- *Conformal invariance and the self avoiding walk*
  G Lawler (Cornell)
- *Granular flows and earthquake faulting*
  J Rice (Harvard)
- *Revisiting the basics of molecular simulations*
  D Frenkel (FOM-Institute for Atomic and Molecular Physics)
- *Zeta functions and random matrix theory*
  P Sarnak (Princeton)

Visits to UK Institutions

When Professor HK Moffatt was Director of the Newton Institute, he started visiting groups of universities in different parts of the UK to listen to views on the ways in which the Institute could add value to the UK mathematical sciences community. This policy has been continued under the present Director and the result to date is shown on the map below. Sir John is always pleased to receive invitations to centres not so far visited.

- Professor Sir John Kingman (Bristol, Edinburgh, Glasgow, London, Manchester, Newcastle, Oxford, Sheffield, Swansea, York)
- Professor HK Moffatt (Birmingham, Glasgow, Leeds, Reading)



S Wilkinson

International Activity

EMS

The European Mathematical Society (EMS) was founded in 1990 in Madralin, near Warsaw (Poland). The meeting which created the EMS was held under the auspices of the European Mathematical Council, chaired by Sir Michael Atiyah before he came the first Director of the Newton Institute.

The purpose of the Society is "to further the development of all aspects of mathematics in the countries of Europe." In particular, the Society aims to promote research in mathematics and its applications, as well as concerning itself with the broader relation of mathematics to society. The EMS acts as an intermediary between mathematicians and those in charge of politics and funds in Brussels; the membership consists of about 50 mathematical societies throughout Europe and around 2000 individual members who have joined through their national societies. More information can be obtained from the Society's website at **http://www.emis.de/**

The current Director of the Newton Institute, Sir John Kingman, became President of the EMS in January 2003. His term of office runs until the end of 2006.

ERCOM

ERCOM ("European Research Centres On Mathematics") is a committee of the EMS consisting of the directors of all the research centres and institutes throughout Europe which have a substantial visitor research programme in the mathematical sciences. ERCOM was founded in 1997 and meets annually. The current chair is Professor M Castellet of the Centre de Recerca Matemàtica in Barcelona. The purposes of ERCOM are:

- to constitute a forum for communication and exchange of information between the centres themselves and with EMS
- to foster collaboration and coordination between the centres and with EMS
- to foster advanced research training on a European level
- to advise the Executive Committee of the EMS on matters relating to activities of the centres
- to contribute to the visibility of the EMS
- to cultivate contacts with similar research centres within and outside Europe

ERCOM is particularly concerned at present with the EC's Framework programmes, and is making representations to ensure that basic research receives sufficient support in both the current and future frameworks, and that the underpinning nature of mathematics in the sciences (and indeed more widely) is properly recognised. ERCOM is also engaged with the European Research Area, with the sustainability of mathematical research in Eastern Europe, and with the participation of female scientists in research institute activities. More information about ERCOM can be obtained from its website at **http://www.crm.es/ERCOM/** or from the Newton Institute. European visitors are particularly encouraged to pick up a leaflet.

EPDI

The European Post-Doctoral Institute for Mathematical Sciences (EPDI) was founded in 1995 by the Newton Institute, the Institut des Hautes Études Scientifiques (Bures-sur-Yvette, France) and the Max-Planck-Institut für Mathematik (Bonn, Germany). Since then six more centres have joined the group, in Leipzig, Vienna, Djursholm, Warsaw, Barcelona and Zurich.

Each year, EPDI offers five two-year grants to young European scientists who have recently completed their PhDs, on condition that they spend at least 18 months in a foreign country and between 6 and 18 months at one of the EPDI institutes. Competition is strong and the scientific quality is high. British applicants, who are currently under-represented, are particularly encouraged.

Further information, including full conditions for grant applications, can be found at the EPDI website, **http://www.ihes.fr/EPDI/**

Other Institute News

Distinguished Visitors

On 6 November 2003 the Institute was visited by Rt. Hon. Charles Clarke MP, Secretary of State for Education and Skills, and Professor Alison Richard, Vice-Chancellor of the University of Cambridge. The visitors had lunch with the Director before embarking on a tour of the Institute, followed by a tour of the nearby Centre for Mathematical Sciences.

On 15 July 2004 H.R.H. Prince Turki Al Faisal, Ambassador of the Kingdom of Saudi Arabia to the UK, visited the Isaac Newton Institute as part of a wider tour of the University of Cambridge. The Ambassador was given a tour of the Institute before signing the Institute Visitors' Book.

Posters in the London Underground

Interest in the poster series designed for the *Maths in the Underground* project (see *Annual Reports* for 1999–2003) continues to be very high, with many further requests for their use. Reprints of the posters are available for purchase at the Mathematical Association's website. Loughborough University has purchased 500 copies of the pocket-sized *Maths Goes Underground* booklet (see last year's *Annual Report*) for inclusion in their information packs for prospective mathematical sciences students. The graphic designer of the poster series, Dr Andrew Burbanks, was an undergraduate student at the University.

The Clay Mathematics Institute has reproduced four of the original poster series for display in the Boston Transit system. This has involved some wording changes for an American audience: see below for an example.

The National Cipher Challenge (run by the University of Southampton) has also purchased 500 booklets to distribute as prizes in their 2004 schools competition, and Universal Pictures will be using the posters as set dressing for their forthcoming film *The Perfect Man*.

Public Understanding of Mathematics

Sir John Kingman, Director of the Institute, gave a public lecture on Saturday 20 March 2004 as part of National Science Week. In his lecture, entitled *Chance and Probability*, he explained how even the most unpredictable things in the world can be studied mathematically. The talk focused on the fact that, although mathematics often deals with things that change in a very predictable way (like the planets moving round the Sun), much in life is quite unpredictable: the weather, the stock market, football results and so on. A high level of audience participation was involved and all those who took part were rewarded with small prizes.

One of the posters as reprinted by the Clay Mathematics Institute

S Wilkinson

Sir John Kingman and his assistants during 'Chance and Probability'

Throughout the year, Dr Robert Hunt, Deputy Director of the Institute, has taken part in several radio and television programmes on topics related to mathematics or to the UK credit industry. He was also involved in programmes discussing the legacy of Sir Isaac Newton, including *Great Britons* on BBC1 and *Newton: The Dark Heretic* on BBC2.

The Institute continues to have strong links with the Millennium Mathematics Project (MMP), a national project jointly organised by the Faculties of Mathematics and Education at the University of Cambridge. Dr Robert Hunt is the Executive Editor of *Plus*, a website run by the MMP which features articles on the applications of mathematics aimed at sixth-formers and the general public.

Awards and Achievements

In July 2004, Sir John Kingman, Director of the Institute, received the honorary degree of Doctor of Science from Brunel University.

The first Director of the Institute, Sir Michael Atiyah, was awarded the Abel Prize for 2004 jointly with Isadore Singer, in recognition of their "discovery and proof of the index theorem, bringing together topology, geometry and analysis, and their outstanding role in building new bridges between mathematics and theoretical physics."

In January 2004, Dr Robert Hunt, Deputy Director of the Institute, was formally appointed as a Special Adviser to the Treasury Select Committee of the House of Commons.

Professor Sir Martin Rees, Astronomer Royal and a long-standing member of the Institute's Management Committee as well as a supporter of the Institute since its foundation, was installed on 15 January 2004 as Master of Trinity College, Cambridge.

Professor Samson Abramsky, a member of the Institute's Scientific Steering Committee (see page 15), was awarded Fellowships of both the Royal Society and the Royal Society of Edinburgh.

Climate Change Management

A symposium entitled *Macro-engineering Options for Climate Change Management and Mitigation* was held at the Newton Institute on 7–9 January 2004 under the auspices of the Tyndall Centre for Climate Research and the Cambridge–MIT Institute. The aim of the event was to identify, debate and evaluate possible macro-engineering approaches to climate change.

Papers and Preprints

In total, 214 papers were produced or in preparation by participants at the Institute during 2003/04 (a complete list is given in Appendix 7). Many of these are included in the Newton Institute's Preprint Series to which participants are encouraged to submit their papers. A web page giving details of the Preprint Series is available at

http://www.newton.cam.ac.uk/preprints.html

Publications arising from Newton Institute Programmes

Two special volumes of the journal *Random Structures and Algorithms* were devoted to the publication of work "presented during, undertaken within, or inspired by" the Newton Institute programme *Computation, Combinatorics and Probability* (July to December 2002; see the *Annual Report* for 2002/03). Part I of the report was published as Volume 24, Issue 3 (May 2004) of the journal and Part II as Volume 24, Issue 4 (July 2004).

Young Scientists

The Institute holds a number of events each year which are specifically targeted at young scientists. In 2003/04 these events included:

- Euroconference on *Spaces of Kleinian Groups and Hyperbolic 3-Manifolds*
- Satellite workshop on *Random Matrix Theory*
- Euroworkshop on *Stochastic Methods in Coagulation and Fragmentation*
- Focus day entitled *Young Person's Guide to Granular and Particle-Laden Flows*
- Satellite conference on *Soft Condensed Matter Physics in Molecular and Cell Biology*
- School on *Recent Perspectives in Random Matrix Theory and Number Theory*
- Euroconference on *Random Matrix Theory and Arithmetic Aspects of Quantum Chaos*
- Euroworkshop on *Matrix Ensembles and L-Functions*

The Institute recognises that junior researchers have much to contribute to and much to gain from Institute programmes and events. In order to maximise the information available to junior researchers, and to facilitate their involvement in Institute activities, we introduced in 1997 a category of Junior Membership of the Newton Institute. To be eligible for membership you must be a Research Student or within 5 years of having received a PhD (with appropriate allowance for career breaks) and you must work or study in a UK University or a related research institution.

Junior Members receive regular advance information about programmes, workshops, conferences and other Institute events via a Junior Members' Bulletin; detailed information about any workshops of an instructional or general nature likely to be of special interest to young researchers; and information about suitable sources of funding or support for visits to the Institute, when available.

The Institute makes available some of its general funds specifically to support junior researchers in Institute activities. Junior Members may apply for grants from these funds. The types of involvement supported include (but are not limited to) attendance at workshops, conferences, etc., and visits of up to two weeks to work or study with longer-term participants in the Institute's programmes. The Institute registered 71 new Junior Members in 2003/04 taking the total to 351 at the end of July 2004. Those wishing to become Junior Members should consult the Institute's web site at

http://www.newton.cam.ac.uk/junior.html

Another source of funding for young scientists is generously provided by the Cambridge Philosophical Society. The following were recipients of bursaries from the Society in 2003/04:

Interaction and Growth in Complex Stochastic Systems

- V Beffara (ENS)
- B Virag (MIT)

Granular and Particle-Laden Flows

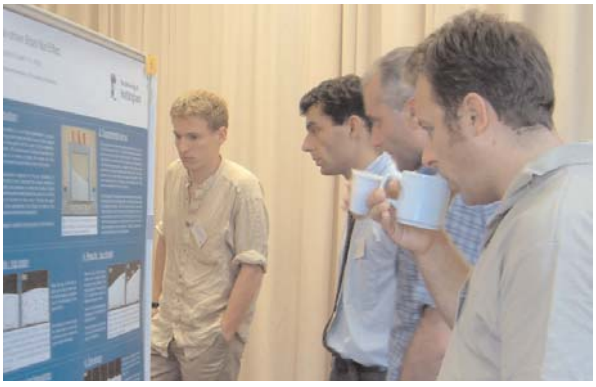
- P Reis (Manchester)
- A Thornton (Manchester)

Statistical Mechanics of Molecular and Cellular Biological Systems

- R Hawkins (Leeds)
- F Mohammad-Rafiee (Institute for Advanced Studies in Basic Sciences)
- P Beales (Edinburgh)

Random Matrix Approaches in Number Theory

- G Ergun (Brunel)
- A Monastra (Dresden)



S Wilkinson

A poster session held during the 'Granular and Particle-Laden Flows' programme

Scientific Steering Committee

Membership of the Scientific Steering Committee at 31 July 2004 was as follows:

Professor S Abramsky FRS FRSE	University of Oxford
Professor JM Ball FRS FRSE	University of Oxford
Professor C Bernardi	University of Paris 6
Professor SK Donaldson FRS	Imperial College London
Professor Sir John Kingman FRS (Secretary)	Director, Newton Institute
Professor TCB McLeish	University of Leeds
Professor JG McWhirter FRS FREng	QinetiQ
Professor EB Martin	University of Newcastle
Professor EG Rees FRSE (Chairman)	University of Edinburgh
Professor G Ross FRS	University of Oxford
Professor BW Silverman FRS	University of Bristol
Professor M-F Vigneras	University of Paris 7
Professor JR Whiteman	Brunel University

The Institute invites proposals for research programmes in any branch of mathematics or the mathematical sciences. The Scientific Steering Committee (SSC) meets in April and October each year to consider proposals for programmes (of 4-week, 4-month or 6-month duration) to run two or three years later. Proposals to be considered at these meetings should be submitted by 31 January or 31 July respectively. Successful proposals are usually developed in a process of discussion between the proposers and the SSC conducted through the Director, and may well be considered at more than one meeting of the SSC before selection is recommended. Proposers may wish to submit a shorter 'preliminary' proposal in the first instance with a view to obtaining feedback from the SSC prior to the submission of a full 'definitive' proposal.

Further details of the call for proposals, including guidelines for submission, can be found on the Institute's website at

http://www.newton.cam.ac.uk/callprop.html

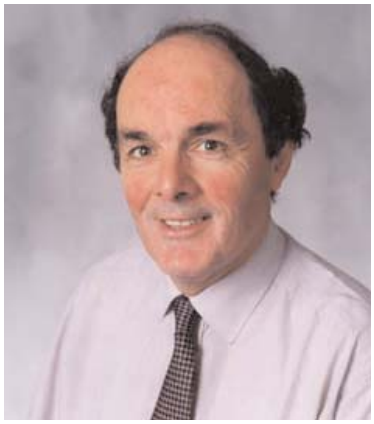
The scientific planning and organisation of each programme are the responsibility of a team of three or four Organisers (aided in some cases by an Advisory Committee). The Organisers recommend participants in the programme, of whom up to twenty can be accommodated at any one time; they also plan short-duration workshops and conferences within the programme, to which many more participants may be invited. Each programme is allocated a budget for salary support, subsistence allowances and travel expenses.

The following members of the Scientific Steering Committee stepped down at the end of their term of service on 31 December 2003:

- Professor AJ Macintyre FRS FRSE (Edinburgh)
- Professor MA Moore FRS (Manchester)
- Professor J Stark (Imperial)

The following new members were elected:

- Professor EB Martin (Newcastle)
- Professor JG McWhirter FRS FREng (QinetiQ)
- Professor M-F Vigneras (Paris)



Professor EG Rees,
Chairman of the Scientific Steering Committee

Scientific Policy Statement

From its inception, it has been intended that the Newton Institute should be devoted to the Mathematical Sciences in the broad sense. In this respect the Institute differs significantly from similar institutes in other countries. The range of sciences in which mathematics plays a significant role is enormous, too large for an Institute of modest size to cover adequately at any one time. In making the necessary choices, important principles are that no topic is excluded *a priori* and that scientific merit is to be the deciding factor.

One of the main purposes of the Newton Institute is to overcome the normal barriers presented by departmental structures in Universities. In consequence, an important, though not exclusive, criterion in judging the 'scientific merit' of a proposed research programme for the Institute is the extent to which it is 'interdisciplinary'. Often this will involve bringing together research workers with very different backgrounds and expertise; sometimes a single mathematical topic may attract a wide entourage from other fields. The Institute's Scientific Steering Committee therefore works within the following guidelines:

(*a*) the mixing together of scientists with different backgrounds does not *per se* produce a successful meeting: there has to be clear common ground on which to focus;

(*b*) each programme should have a substantial and significant mathematical content;

(*c*) each programme should have a broad base in the mathematical sciences.

Research in mathematics, as in many other sciences, tends to consist of major breakthroughs, with rapid exploitation of new ideas, followed by long periods of consolidation. For the Newton Institute to be an exciting and important world centre, it has to be involved with the breakthroughs rather than the consolidation. This means that, in selecting programmes, a main criterion should be that the relevant area is in the forefront of current development. Since the Institute's programmes are chosen two to three years in advance, it is not easy to predict where the front line will be at that time. The best one can do is to choose fields whose importance and diversity are likely to persist and to choose world leaders in research who are likely to be able to respond quickly as ideas change.

Although the novelty and the interdisciplinary nature of a proposed programme provide important criteria for selection, these must be subject to the over-riding criterion of quality. With such a wide range of possibilities to choose from, the aim must be to select programmes which represent serious and important mathematical science and which will attract the very best mathematicians and scientists from all over the world. However, the Institute is receptive also to proposals of an unorthodox nature if a strong scientific case is made.

Although the Institute operates on a world-wide basis and contributes thereby to the general advancement of mathematical science, it must also be considered in the context of UK mathematics. A natural expectation of all those concerned is that each programme will be of benefit to the UK mathematical community in a variety of ways. If the UK is strong in the field, UK scientists will play a major part in the programme; if the UK is comparatively weak in the field, the programme should help to raise UK standards. Instructional courses, aimed primarily at younger researchers and research students, play a vital role here.

Because of the wide base of support for the Newton Institute in the EPSRC and elsewhere, the Institute's programmes represent, as far as possible, an appropriate balance between the various mathematical fields. In order to retain the backing of the mathematical and scientific community, the Institute runs programmes over a wide range of fields and, over the years, achieves this balance. Such considerations, however, are secondary to the prime objective of having high quality programmes.

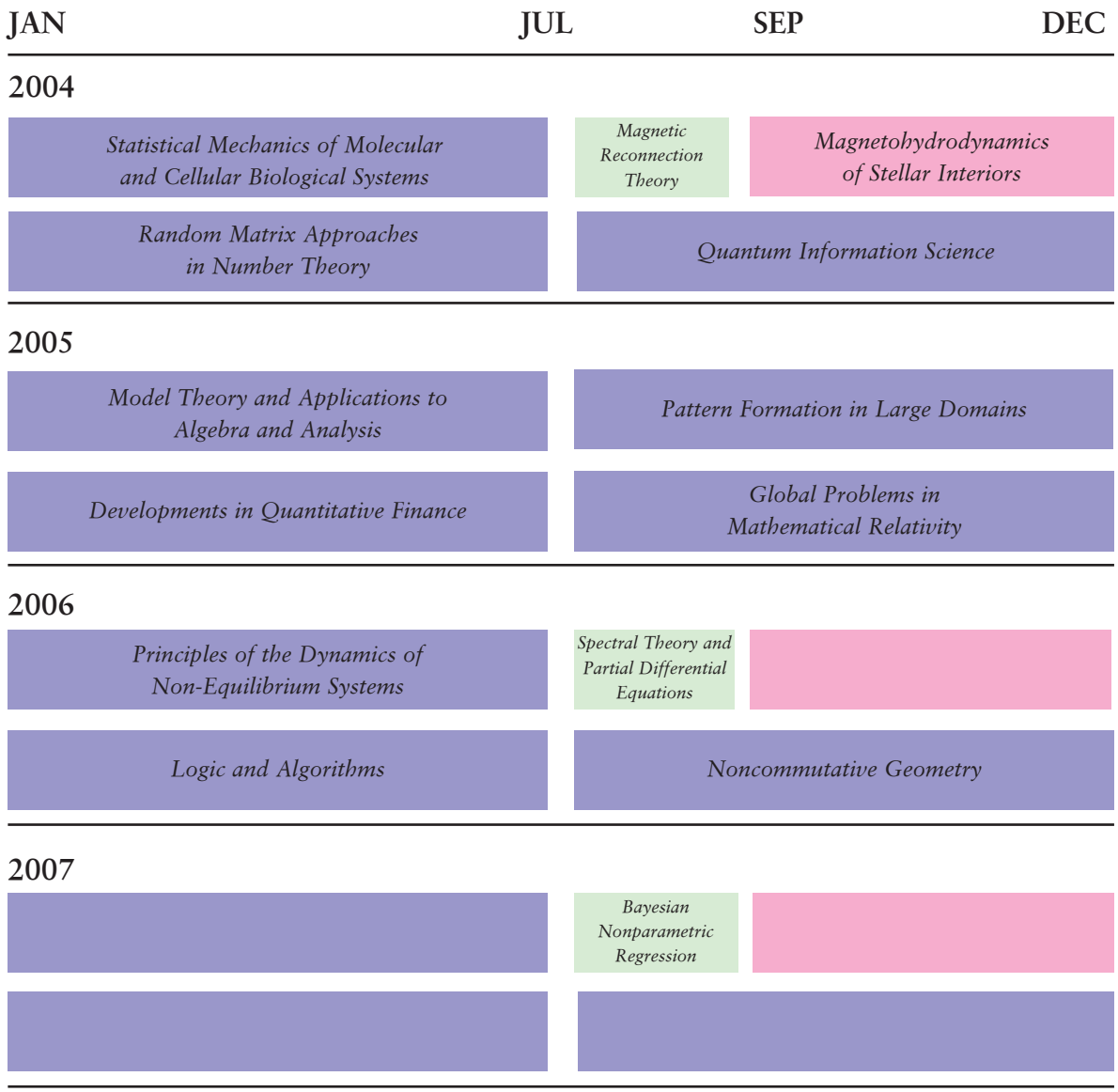
Future Programmes

The diagram below shows the forthcoming programmes which have so far been selected by the Scientific Steering Committee. To participate in a workshop, registration is required. For longer-term participation in a programme, an invitation is usually required, and applications are best made to the programme Organisers in the first instance. Further details of each of these programmes, including

- the scientific content and background
- the names of the Organisers
- the names of those who have so far been invited to take part in the programme
- contact details
- dates, topics and information about workshops which will take place during the programme

can be found on the Newton Institute website at **http://www.newton.cam.ac.uk/programmes/**

Further information on how to participate in Newton Institute programmes can be found at **http://www.newton.cam.ac.uk/participation.html**



Management Committee

Membership of the Management Committee at 31 July 2004 was as follows:

Dr A Bramley	EPSRC
Professor J Brindley	Co-opted at the discretion of the Committee
Professor B Bruce	London Mathematical Society
Professor WJ Fitzgerald	Council of the School of Technology
Professor GR Grimmett	Head of Department, DPMMS
Professor EJ Hinch FRS	Trinity College
Dr RE Hunt (Secretary)	Deputy Director, Newton Institute
Professor PT Johnstone	St John's College
Professor Sir John Kingman FRS	Director, Newton Institute
Professor PV Landshoff (Chairman)	General Board
Professor TJ Pedley FRS	Head of Department, DAMTP
Professor EG Rees FRSE	Chairman of Scientific Steering Committee
Professor Sir Martin Rees FRS	Council of the School of Physical Sciences
Dr C Teleman	Faculty of Mathematics

The Management Committee is responsible for overall control of the budget of the Institute, and for both its short-term and long-term financial planning. The Director is responsible to the Management Committee, which provides essential advice and support in relation to fund-raising activity, employment of staff at the Institute, appointment of organisers of programmes, housing, library and computing facilities, publicity, and general oversight of Institute activities.

Its aim is to facilitate to the fullest possible extent the smooth and effective running of the visitor research programmes of the Institute and all related activities. The Committee is especially concerned with the interactions between the Institute and its funding bodies, particularly the UK Research Councils, Cambridge University, the Cambridge Colleges, the London Mathematical Society, the Leverhulme Trust and others. It generally meets three times a year.

Staff of the Institute

The staff (full-time and part-time) of the Institute at 31 July 2004 was as follows:

- Amy Abram, Conference and Programme Assistant
- Dr Mustapha Amrani, Computer Systems Manager
- Tracey Andrew, Conference and Programme Secretary
- Lynn Berry, Catering Assistant
- Jody Botting, Technical Assistant
- Jonathan Chin, Deputy Computer Systems Manager
- Esperanza de Felipe, Housing Officer
- Kate Gilbert, Director's Administrative Assistant (appointed from 1 August 2004)
- Dr Robert Hunt, Deputy Director (on leave)
- Professor Konstantin Khanin, Hewlett-Packard Senior Research Fellow
- Professor Sir John Kingman FRS, Director
- Margo Kirk, Information Assistant (acting)
- Doreen Rook, Clerk
- Beata Scott, Receptionist
- Christine West, Institute Administrator
- Sara Wilkinson, Information Officer
- Stephen Williams, Senior Accounts Clerk
- Sarah Wygard, Information Assistant (on leave)

Hewlett-Packard Senior Research Fellow

Report from Professor Kostya Khanin

This was the final year of my Hewlett-Packard Senior Research Fellowship. From July to December 2003 I worked mainly on running the Newton Institute programme *Interaction and Growth in Complex Stochastic Systems*. As one of the five Organisers of this programme, I was directly involved in many of its activities. In my opinion the programme was very successful. For me personally it resulted in two new research projects which originated directly from discussions held during the programme. The first is a joint research project with Stas Molchanov (North Carolina at Charlotte) and Viet Ha Hoang (Cambridge). In this project we are studying localization and pinning for directed polymers in quasi-stationary random potentials. We also consider localization for the corresponding Schrödinger operators. The second project, joint with Jeremie Bec (Observatoire de la Côte d'Azur) and Bernard Derrida (École Normale Supérieure), deals with KPZ scalings for directed polymers and optimal paths in 2D disordered media.

From January 2004 I continued research on three different topics in the theory of dynamical systems. These three topics, although quite different technically, are related through the idea of renormalizations. Joao Lopes-Dias (Lisbon), Jens Marklof (Bristol) and I are writing a paper on renormalizations, multi-dimensional continued fractions and KAM theory. Alexey Teplinsky (Kiev) and I are working on smoothness of conjugacies for critical circle maps. I am also involved in a joint research project with a group of mathematicians from Samarkand (Uzbekistan). In this project, sponsored by the Royal Society, we are studying rigidity theory for multi-modal circle maps with singularities.

The Hewlett-Packard Senior Research Fellowship which I have held for 5 years was designed as a bridge between the Newton Institute and the Basic Research Institute in the Mathematical Sciences (BRIMS) in Bristol. For the first two years I had strong connections with a very inspiring research group there. BRIMS was a unique institution, founded as an interface between academia and the Hewlett-Packard Research Labs in Bristol. Most unfortunately, BRIMS was closed back in 2002. I feel very privileged having been connected with BRIMS for almost 3 years. I am sure that everybody who visited BRIMS even for a short time will confirm that it was an extraordinary research institution with a unique atmosphere. I do believe that the ideas behind BRIMS are still very much alive and that similar institutes will be created in the future by many high-tech companies.

Overall the Fellowship was a fantastic 5 year period: definitely the most active and enjoyable research period in my life. In my opinion the Isaac Newton Institute is the best place in the world for mathematical sciences. Very interesting programmes, a constant flow of exceptionally strong visitors, the close proximity of DPMMS and DAMTP at the University of Cambridge, ideal working conditions, friendly and extremely competent staff – all these contribute to a unique research atmosphere and environment at the Newton Institute. I am deeply grateful for the wonderful opportunity I have had and will always remember these five happy years.

During the period of my Fellowship I authored or co-authored a total of 21 papers. A further 5 are still in preparation and will hopefully be finished in the very near future. Full details and references can be found at

http://www.newton.cam.ac.uk/reports/hp.html

S Wilkinson

Kostya Khanin playing pétanque at the Institute

Spaces of Kleinian Groups and Hyperbolic 3-Manifolds

21 July to 15 August 2003

Report from the Organisers: *Y Minsky (Stony Brook), M Sakuma (Osaka), C Series (Warwick)*

S Wygard

Left to right: Y Minsky, C Series and M Sakuma

The modern subject of Kleinian groups and hyperbolic 3-manifolds divides roughly into three phases: the Ahlfors–Bers school (before about 1980), the Thurston era (1980–95), and post-Thurston. Thurston's ideas, which centred on showing that very many 3-manifolds can be endowed with a hyperbolic structure, revolutionised the field. After more than a decade of turmoil spent debating and consolidating his insights, by the mid-'90s we appeared to have settled down on a number of hard problems which still seemed pretty far out of reach. The last two or three years, however, have seen a series of profound and far reaching breakthroughs, with new results and techniques appearing almost monthly, to the point where many of these old problems are now close to resolution.

This meeting turned out to be the international gathering at which this plethora of new results was disseminated to a wider audience for the first time. Almost all the primary contributors took part, among them a remarkable group of young people who between them are leading much of the advance. Quite how rapid progress has been only became apparent to most of us during the meeting. Listing individual talks and publications cannot fully do it justice; the programme will be remembered as the moment at which all of these new ideas were brought together, laying a common foundation for future work.

Problems and Solutions

The programme was especially concerned with the classification and location of discrete groups in the ambient space of all representations from the fundamental group of some fixed 3-manifold into SL(2,ℂ). Three major problems were open when the meeting was first planned: Marden's Tameness Conjecture, the Bers Density Conjecture and Thurston's Ending Lamination Conjecture. Of these, the last two have now been proved for all tame groups and there has been a huge extension in the class of groups known to be tame.† Much of our activity naturally centred round understanding this flurry of work.

The simplest class of Kleinian groups is the geometrically finite ones for which there is a finite sided fundamental polyhedron; the deformation theory of these groups was worked out by Ahlfors, Bers and Marden and largely understood pre-Thurston. A hyperbolic 3-manifold is called tame if it is homeomorphic to the interior of a compact 3-manifold. Geometrically finite groups are necessarily tame. Marden conjectured in the '70s that all (finitely generated) hyperbolic 3-manifolds are tame. Major progress has been made in joint work of Brock, Bromberg, Evans and Souto, culminating in a proof by Brock and Souto that all algebraic limits of tame groups are tame. A corollary is the Ahlfors measure conjecture for tame groups: the limit set has either full or zero Lebesgue measure.

Ahlfors–Bers theory shows that geometrically finite groups are determined by the analytic (Teichmüller) data of their ends. Thurston and Bonahon showed in the '80s that if the 3-manifold has incompressible boundary, then each non-geometrically finite end contains a sequence of

†Since this report was written, proofs of the Tameness Conjecture have been announced independently by Agol and by Calegari and Gabai.

S Wygard

Participants at the Euroconference 'Spaces of Kleinian Groups and Hyperbolic 3-Manifolds'

closed geodesics which exit the end and which limit on an 'ending lamination', from which it can be shown that the end is tame. The Ending Lamination Conjecture (ELC) asserts that a hyperbolic 3-manifold is completely determined by these 'end invariants': the analytic data of each geometrically finite end and the ending lamination of the rest. In the last year Brock, Canary and Minsky have completed the proof of the ELC for all tame hyperbolic 3-manifolds. The proof proceeds by decomposing the manifold into 'blocks' whose arrangement is determined from the end invariants by a certain path through the curve complex. This is a simplicial complex that encodes the combinatorial structure of the set of simple loops on a surface. This path is shown to control the the arrangement of short geodesics, hence the geometry of the blocks, from which it is possible to reconstruct the manifold up to quasi-isometry.

The Bers Density Conjecture states that every finitely generated Kleinian group can be approximated by geometrically finite ones. Contributions from many people, including most recently Brock, Bromberg, Canary, Evans, Kleineidam, Ohshika and Souto, have culminated in a proof of this conjecture for all tame groups. A crucial step was an innovative approximation technique introduced by Bromberg. Together with many other recent developments, this rests on the deformation theory of cone manifolds. Initiated by Kerckhoff and Hodgson in the mid-'90s, this technique has been honed into a powerful tool. Recent refinements allow one to construct and control deformations of groups in very precise ways. Another important contribution was a new criterion for the existence of algebraic limits due to Kleineidam and Souto.

Structure of the Programme

Aside from the very intense Euroconference which took place in the third week, the programme was kept fairly unstructured to allow maximum time for informal interaction between participants. Many commented on just how ideally suited the architecture of the Institute is to this purpose. From early to late, groups of participants were to be heard in lively conversation on all sides.

Organised seminars, especially in the second week, gave all participants who wished the opportunity to speak outside the workshop. Since the conference programme was necessarily very crowded, this was much appreciated, and several additional talks were given by popular request. The final week was especially valued by those who were able to stay on, producing an interesting mix of people and some unexpected interactions.

A much commented on and appreciated feature was the mix of participants from the different schools in Europe, the USA and Japan. Many people met their overseas counterparts for the first time and numerous new transcontinental collaborations were initiated. We shall be pleased if this leads to future enrichment and evolution of the field.

The several computational experts (Dumas, Wada, Wright, Yamasita) made a considerable contribution, producing new computations and graphics 'to order' in response to the questions and conjectures of participants. Their graphics programs received much wider explanation and publicity than hitherto and one can anticipate that this will be very beneficial for future developments.

Spaces of Kleinian Groups and Hyperbolic 3-Manifolds

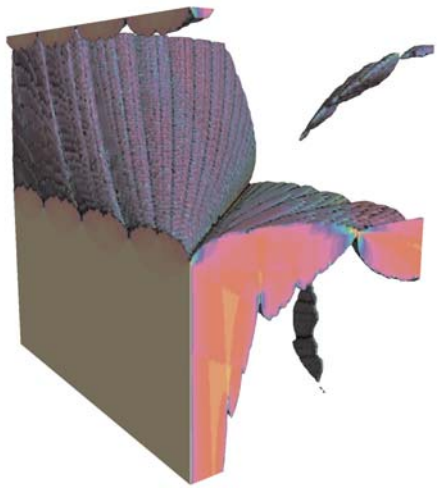
Euroconference, 3–8 August 2003

This conference was extremely successful and could not have been better timed. We were over-subscribed and in the event exactly 100 people took part, among them almost all the main contributors to recent research. There was a very good mix of ages from the most senior figures to new graduate students.

There was a full programme of talks which maintained a notably high standard. Speakers included a substantial number of very talented young people; others presented their work in two lively poster sessions. Canary and Minsky between them outlined the proof of the ELC while the talks of Bromberg, Evans and Souto centred on the Density Conjecture and limits of tame groups. Kerckhoff explained some refinements of deformation theory which are important for many applications.

A theme common to many of the talks, especially those of Souto, Miyachi and Ohshika, was the topological and analytic machinery needed to extend results from the incompressible boundary case to all tame groups. Often building on the new results, we now have a much better understanding of the topology of deformation spaces, another of the field's important open problems. For example Holt presented results about the rather mysterious 'bumping' between various components of the discreteness locus.

Another conjecture of Thurston is that a Kleinian group is determined by the geometry of its convex core boundary. While important questions remain,



M Wada and Y Yamasita

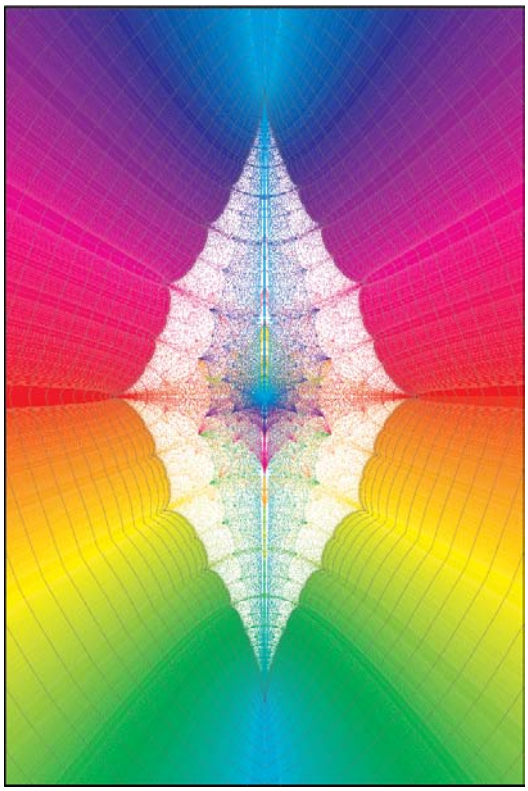
A three dimensional slice of quasifuchsian space for once punctured tori. The picture shows a region between a Maskit slice (tr=2, front left face) and McMullen's favourite slice (tr=2+6i, back right face)

Lecuire has recently completely characterised the possible bending laminations. In the case when the bending lines are closed curves, Series and Choi used cone manifold theory to show that the traces of the bending lines are local parameters for the deformation space. This is a significant step towards obtaining pictures of the discreteness locus in higher dimensional deformation spaces.

Another theme was the combinatorial structure of Teichmüller spaces, mapping class groups, and the complex of curves on surfaces. This last played a crucial role in the proof of the ELC. Hamenstädt and Bowditch in particular gave beautiful talks discussing their results which simplify and extend important earlier results of Masur and Minsky. Hamenstädt's results actually go much further by analysing the quasi-isometry problem for the mapping class group and solving the "rank conjecture" for quasi-flats in the group. Masur, Rees and Wolpert all discussed various closely related aspects of the geometry of Teichmüller space and the complex of curves.

A somewhat novel feature, which met with participants' approval, was that the first day was devoted mainly to experimental computer graphics. Such graphics have provided insights and underpinned or inspired much recent research,

D Wright



One of the conference postcards, showing the Riley Slice of Schottky space. Each point represents a group with two parabolic generators. Outside the 'eye' all groups are discrete and free. The colours and contours describe the shape of the convex hull. The inner 'dust' marks groups with an extra parabolic.

notably concerning the shape and topology of deformation spaces. Several talks explaining algorithms led to lively discussions, with new ideas actually being implemented during the conference. One such was the first ever picture of 3-dimensional slices of the discreteness locus in a 4-dimensional parameter space, made using software developed for medical imaging (see figure on the opposite page).

It was a packed week, with a conference dinner in Emmanuel College and a very enjoyable Book Evening hosted by Cambridge University Press. In place of the traditional T-shirts, we celebrated the input of computer graphics by distributing a set of six postcards of Kleinian group pictures, sponsored by Cambridge University Press.

Participants will remember the first week of August as the hottest yet on record; the success of the conference can be in part measured by the fact that the lecture room remained full to the end despite the almost overwhelming heat.

Outcomes

Participants agreed that this programme will be remembered as a definitive moment for the field. It brought together almost all the major players and introduced the young people who have recently made such major contributions to the wider community. It played a crucial role in disseminating the torrent of new ideas and facilitated numerous new contacts between key researchers. There is no doubt that it will have set the agenda for the next phase of research. By the end of the meeting, there was a general realisation that the post-Thurston subject has fully come of age.

Aside from the numerous individual publications and collaborations which will result, there will be conference proceedings edited by the three organisers. This will be a companion volume to *Kleinian Groups and Hyperbolic 3-Manifolds*, the Proceedings of the Warwick workshop, September 2001, which has recently appeared as LMS Lecture Notes **299** (2003).

We conclude with a few comments from participants:

"I have attended many conferences in Kleinian groups, but this has been the best, the most comprehensive, and stimulating, that I have attended."

"The main purposes of the programme were to reveal, to the broader community, the recent ground-breaking techniques, results and experimental work in the area. In this regard, it succeeded beyond my wildest expectations."

"It was a brilliant idea to organise this workshop. Thank you very much to the Newton Institute and all the people who helped us during our wonderful stay in Cambridge."

Interaction and Growth in Complex Stochastic Systems

21 July to 19 December 2003

Report from the Organisers:
E Bolthausen (Zurich), K Khanin (Newton Institute), G Lawler (Duke), JR Norris (Cambridge), YM Suhov (Cambridge)

S Wilkinson

JR Norris and K Khanin

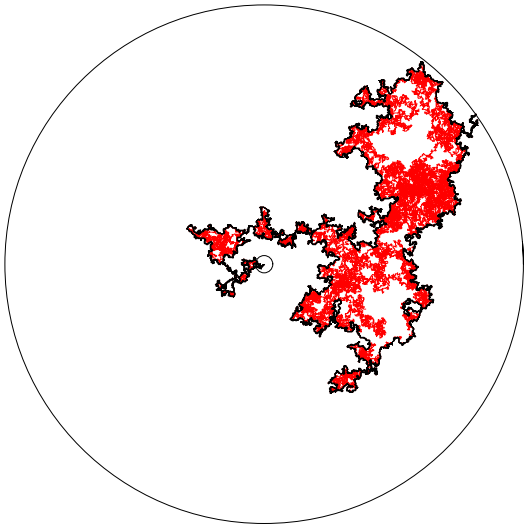
Scientific Background

Random growth processes play an increasingly important role in various parts of pure and applied mathematics, with applications in many areas of natural science (physics, chemistry, biology, environmental studies, computer science), engineering (including material sciences and management), humanities (economics, finance, social sciences) and medicine. Traditionally, growth processes were studied in many disciplines in a rather isolated fashion which can be explained by a broad variety of models and phenomena. However, major recent advances have fundamentally changed our perceptions of well established problems, and these have tended to unify the area. The aim of this programme was to put together, in a more systematic way, the various strands which have been discovered and studied over the last 10 years, with the main focus on the probabilistic study of random growth processes emerging in theoretical and mathematical physics.

Random processes are often understood by means of an asymptotic limit in which the number of basic random components becomes large. Classical examples of behaviour which can be manifest in such a limit are the law of large numbers and the central limit theorem. These two examples apply in contexts where the interaction between typical random components becomes negligible in the limit. However, there are many extremely important physical models where such an asymptotic decorrelation does not hold. Such models correspond to a critical behaviour where interaction is strong and statistical scaling properties are highly nontrivial. Understanding of the asymptotic properties for such systems is one of the most important problems in modern probability theory.

This programme was focused on problems from a number of contexts where strong random interactions give rise to non-classical limiting behaviour. These include random walks in a random environment and interactive random walks, interfaces in growth models and equilibrium statistical mechanics, coagulation and fragmentation processes, conformally invariant scaling limits and random matrices. The range of possible limiting behaviours is rich and introduces to probability new connections with other areas of mathematics and physics. Of particular importance is a connection with conformal field theory. Renormalization group ideology, which was developed by physicists over the last 30 years, predicts the appearance of universal scaling and conformally invariant random fields characterizing statistical behaviour in critical situations.

However, rigorous results in this direction were out of reach until very recently when new connections with complex analysis and the Loewner differential equation were discovered. Powerful new techniques are emerging which make possible the computation of exact asymptotics along with a rigorous understanding of convergence. These new ideas and techniques were one of the main topics of the programme.



A planar Brownian motion and its outer boundary

Structure of the Programme

The programme attracted a very strong contingent of nearly eighty long-term and sixty short-term visitors. The highest periods of attendance were built around the four workshops, one of which (the NATO ASI) had a substantial instructional component. In between, a regular seminar series was run with two talks weekly. The inspiring atmosphere of the Isaac Newton Institute stimulated intensive interaction between the participants and quite a few new collaborations started during the programme.

Workshops

Conformal Invariance and Random Spatial Processes

NATO Advanced Study Institute and Satellite Workshop at the International Centre for Mathematical Sciences, Edinburgh, 8–19 July 2003

Organisers: K Khanin, G Lawler and JR Norris

This NATO Advanced Study Institute (ASI) and EPSRC-funded workshop took place at the University of Edinburgh and was organised by the International Centre for Mathematical Sciences (ICMS).

Recent exciting advances at the intersection of probability and complex variable theory have made it possible to understand mathematically ideas that arose in theoretical physics. It had been conjectured that a number of two-dimensional systems in statistical physics such as percolation, the Ising model and self-avoiding walks have scaling limits that are invariant under conformal transformations (i.e., they look similar when subjected to a change that locally looks like a scaling factor and a rotation). Physicists had used this conjecture and a mathematically non-rigorous technique, conformal field theory, to make predictions about these systems. Numerical simulations had given strong support to these conjectures, but until a few years ago they were unproven.

The meeting started with an intensive instructional NATO ASI with five mini-courses given by the leading experts in the field. This structure gave the chance for many participants to get enough understanding of the subject to follow the research part of the meeting. Two short courses were given by G Lawler and W Werner on Schramm–Loewner evolution (SLE), a process introduced by Oded Schramm, that is the missing ingredient needed to understand these limits rigorously. Other short courses were given in closely related areas: J Cardy, a theoretical physicist, gave a course for mathematicians on Coulomb gas methods; K Johannson discussed another exciting area in probability, namely random matrix theory and its applications; and R Kenyon lectured on combinatorial and conformal geometric methods to understand lattice dimers and related models.

The workshop which followed the ASI featured experts in probability, theoretical physics and analysis who gave the state of the art of this area. A number of the lecturers discussed recent results in a programme to construct conformal field theories using Schramm–Loewner evolution. This is an exciting development for both the physics and mathematics communities. Physicists are, for the first time, understanding the process that arises as boundaries in statistical physics systems. Mathematicians can use SLE to understand the non-rigorous arguments of conformal field theory that heretofore appeared very mysterious.

S Wagand

Participants at the workshop 'Random Walks in Random Environment'

Other talks focused on properties of SLE and a number of discrete models – there are still many open questions concerning the convergence of discrete models to SLE. There were also talks on related areas, e.g., new results on spin glasses and dynamical systems.

The last session of the workshop was entirely dedicated to open problems in this very new and active research area. A web-based e-publication is in preparation which will contain all the materials of minicourses and most of the research talks. This will be available for free access by anyone interested in the subject.

Random Walks in Random Environment

Workshop, 18–22 August 2003

Organisers: E Bolthausen and A-S Sznitman

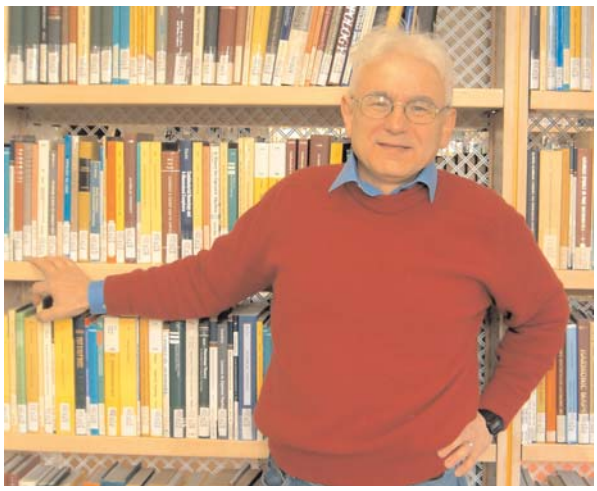
The workshop brought together leading scientists working on random walks in random environments (RWREs) and on topics closely related to this, such as random walks in random potentials, directed polymers in random environments, random walks on percolation clusters, reinforced random walks, and passive tracer models.

RWREs have proved to be a source of challenging problems in past years, and much progress has taken place recently. New developments were presented at the workshop. For instance, regeneration times have proved to be a powerful tool. These allow the introduction of a kind of independence structure, but the application is delicate.

Of considerable interest are random walks in random potentials. For time independent potentials, the asymptotic behaviour can be non-diffusive, and particles move to 'traps' where they stay for a long time. This is now quite well-understood. The theory in the important time-dependent case is much less developed, but there has recently been considerable progress here too. This case is closely related to directed polymers in random environments, a model with a long history which is of particular importance because of its relations with turbulence, with random growth models, with first passage percolation and with spin glass theory, to name only a few. Rigorous results have been quite rare, especially for the high disorder situation. At the workshop, there were several talks reporting on recent results in this area. Some striking results have recently been obtained using martingale methods. These were presented in detail by several authors. There were also a number of talks on different but closely related models, including random catalysts, heat kernel estimates on percolation clusters, and reinforced random walks.

The Newton Institute provided an excellent environment for an extremely lively, communicative and informative workshop which gave a fairly comprehensive overview of the most important recent developments in this rapidly growing field.

S Wilkinson



YM Suhov

Random Matrix Theory

Satellite Workshop at Gregynog, University of Wales, 14–19 September 2003

Organisers: I Davies, L Pastur, YM Suhov and A Truman

This workshop, supported by the European Science Foundation through its project *Random Dynamics in Spatially Extended Systems*, brought together about thirty leading researchers in this exciting field of modern mathematics. They discussed methods and results from classical and functional analysis, combinatorics, integrable systems, number theory, operator algebras and probability, with applications in quantum mechanics, quantum field theory, statistical mechanics and condensed matter theory. The list of problems under consideration included the Ulam problem of the longest increasing subsequence in a random permutation, related problems about asymptotics of Toeplitz determinants, directed first-passage percolation, asymptotic distributions in queueing systems, random Young tableaux, partitions of natural numbers, zeros of the Riemann zeta function and Anderson localisation. According to the common opinion of many participants, the main success of the workshop was that it brought together a wide circle of interested academics including P Bleher (Purdue), N O'Connell (Warwick), K Johansson (Stockholm), K McLaughlin (North Carolina), A Soshnikov (California), H Spohn (Munich) and others, which stimulated exchange of ideas and contributed to an inspiring meeting.

It was the unanimous opinion that Gregynog Hall (associated with the University of Wales and located in beautiful local countryside) provided excellent working and recreational facilities, and that the local organisers and the staff demonstrated the highest degree of hospitality. The workshop will certainly be remembered by all present with affection and appreciation.

Stochastic Methods in Coagulation and Fragmentation

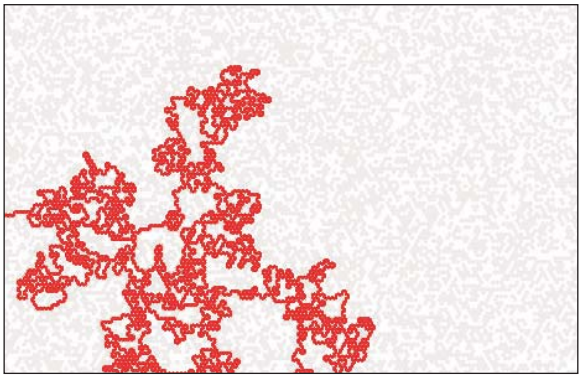
Euroworkshop, 8–12 December 2003

Organisers: JR Norris, M Kraft and W Wagner

This workshop was the first substantial international meeting to bring together probabilists and analysts working on coagulation and fragmentation. Activity in this area has intensified in the last ten years for a number of independent reasons. Probabilists and analysts have developed a greater facility in understanding the evolution of large and complex systems, and have recognised the scientific and mathematical interest of coagulation and fragmentation. At the same time modern computing resources offer the possibility of simulating and predicting the behaviour of these systems. The workshop revealed significant advances in the structural understanding of probabilistic models and in the behaviour of these models in long time limits, as well as in scaling limits and gelation for analytic models.

The workshop attracted seventy participants. There was also input from industry in the form of a special session. All of the participants were exposed to this subject from at least one new perspective and many took up the opportunity to explore new directions with the experts present at the workshop.

The programme comprised four lectures of one hour on most days. On the probabilistic and combinatorial side the speakers were J Bertoin, J Schweinsberg, G Miermont, D Aldous, P Chassaing, M Deaconu, N Fournier, A Lushnikov,



The boundary of a percolation cluster on the triangular lattice

O Zeitouni, J Berestycki and J-F Le Gall. On the analytic side there were talks by P Laurencot, M Escobedo, B Niethammer, F Leyvraz and V Kolokoltsov. W Wagner addressed some numerical issues. M Kraft led a session in which A Bayly and P Mort, both of Proctor & Gamble, and C von Toerne of Bayer gave a valuable industrial perspective.

Outcome and Achievements

The programme attracted a large number of participants including many of the leading experts in probability theory and related fields.

Feedback from the participants was positive, praising the research environment of the Institute and its facilitation of interaction and the development of new collaborations. In addition to the four workshops described above, a seminar was held twice weekly and a study group on SLE was held weekly.

A significant outcome of the programme was the dissemination of recent work on SLE to a wide audience of probabilists, beginning with the courses by Lawler and Werner and continuing in seminars and the study group. Many participants mentioned the impact of this exposure to their ongoing work. During the programme, progress was made by Lawler on some new discrete models which converge to SLE, and by Werner on the Brownian loop soup and SLE curves when the central charge is positive. Extensions to Riemann surfaces were the focus of work by Makarov and Friedrich.

Progress was made in a number of important problems for lattice-based statistical mechanics, notably in metastability, droplet formation and random walks in a random environment. Bovier and den Hollander proved metastability results for Kawaski dynamics at low temperature and low density in dimensions two and three, describing the behaviour of the critical droplet. Hryniv, Ioffe and Kotecky obtained sharp asymptotics for the critical region for droplet formation and also central limit-type results for certain functionals of random phase separation lines, such as area or local magnetisation. Shlosman completed a work with van Enter on phase transitions in gauge theories with continuous symmetry and started a project with Ioffe modelling the process of droplet condensation of hot ideal gas on a cold substrate. Slade and van der Hofstad obtained new results for percolation critical values in high dimensions. J van den Berg completed a work on self-destruction percolation. Comets collaborated with Yoshida and Zeitouni on some problems in random media and in random walks in a random environment.

A class of random media termed quasi-stationary was studied by Boldrighini, Khanin, Minlos, Molchanov and Pellegrinotti. In this model the random potential is formed by the product of two factors: one depending on space and the other on time. It turns out that if the probability distribution for the space factor has exponential tails then the corresponding random walk will be localised in the trapping region, while in the bounded case numerical studies suggest that random walk exhibits KPZ scalings.

Hydrodynamic limits of many-particle systems and of interfaces were studied by many participants, including Conlon, Funaki, Ioffe and Norris.

Koenig and Moerters completed a work on the intersections of several Brownian motions.

A major theme was random matrix theory and its relation to stochastic growth models. Prähofer and Spohn made progress in understanding the fluctuations of stationary, as well as droplet-type, one-dimensional growth models and related multi-matrix ensembles. Bleher worked on a Gaussian

S Wilkinson

Participants attending the Euroworkshop 'Stochastic Methods in Coagulation and Fragmentation'

random matrix model with external source. O'Connell and Johansson were able to interpret a probabilistic model for the Riemann zeros in terms of the eigenvalues of Brownian motion on a certain symmetric cone.

Hambly and Martin studied a certain two-dimensional last passage percolation problem, which may also be considered as a growth model, obtaining good estimates on the passage time.

Goldsheid proved a generalisation of the Thouless formula to non-Hermitian Jacobi matrices.

Kesten and Sidoravicius worked on a model for the spread of infection by random walkers on a multi-dimensional lattice, with infection on contact. They determined the asymptotic shape of the epidemic and also showed that if individuals can recuperate, and do so fast enough, then the infection dies out.

M Penrose made studies of directed geometrical random graphs, making links with the Poisson–Dirichlet distribution and fragmentation processes. He also collaborated with Yukich on random deposition models.

The mass-flow process is used in the simulation of certain coagulation processes. Work by Wagner established that this process explodes for any coagulation kernel homogeneous of degree greater than one. This is relevant to the detection of gelation for such kernels.

Above we have described some of the results obtained by the participants during the programme. The programme has certainly stimulated an intensive exchange of ideas between participants; new collaborations have started and we are confident that they will lead to new important results in the near future, which will stand as the main achievement of the programme.

Granular and Particle-Laden Flows

1 September to 19 December 2003

Report from the Organisers: *JMNT Gray (Manchester), K Hutter (Darmstadt), JT Jenkins (Cornell), T Mullin (Manchester)*

S Wilkinson

Left to right: T Mullin, K Hutter, JMNT Gray and JT Jenkins

Scientific Background

This research programme at the Newton Institute was devoted to improving the understanding and mathematical modelling of granular and particle-laden fluid systems as they arise in nature, in the laboratory and in industry. Geophysical examples of granular and particle-laden flows include rock avalanches, debris flows, mud flows and turbulent boundary layers with suspended particles, such as volcanic ash flows, underwater turbidity currents and powder snow avalanches. Industrial examples include flows of cereals, pharmaceuticals, alumina, coal and concrete, in storage facilities, production lines, power stations and construction sites. Although these examples might seem to be of disparate nature, in fact, they have many common features. An objective of the programme was to develop synergies between the various mathematical approaches.

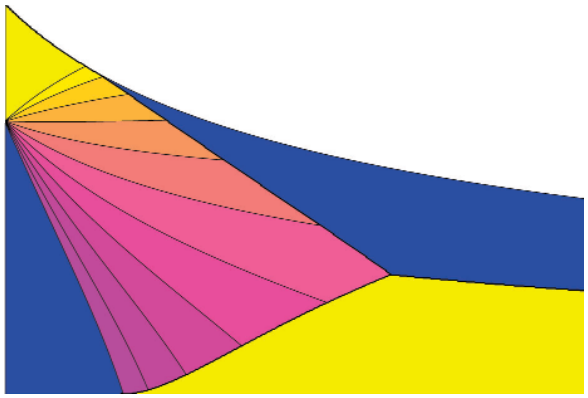
Mathematicians and physicists are fascinated by such flows because they involve a wide range of flow regimes and abrupt transitions between them. Granular and particle-laden flows often involve grain segregation by size, mass, or other properties. Such flows often exhibit interesting patterns, chaotic motion, and transitions between structure and chaos.

The diverse regimes of physical behaviour require different mathematical models: methods of both nonlinear continuum mechanics and non-equilibrium statistical mechanics are employed; computer simulations that are the analogue of molecular dynamic techniques are used to inform modelling of the solid, fluid and gaseous states, including the transition from one to the other; concepts from continuum mixture theory and turbulence are often required to describe the interaction between the fluid and the grains in both dense granular flows with little interstitial fluid as well as in flows of dilute suspensions; and scaling arguments are often helpful in guiding theoretical formulations.

Prior to the programme, the mathematical description of granular and particle-laden flows proceeded on a case-by-case basis and a unified description, developed from first principles, seemed out of reach. Because such a description was likely to involve a range of complex and sophisticated theoretical concepts and to require an interdisciplinary approach, the time was felt to be ripe for a concerted effort among mathematicians, physicists and engineers to focus on the fundamental mechanisms responsible for the observed phenomena and to attempt to unify the seemingly disparate models.

Organisation and Participation

This four-month programme involved 42 long-term visitors, 26 of them from the UK. There were also 55 short-term visitors, 28 from the UK. An additional 141 individuals, 76 of them from the UK, participated in the two workshops and the five focus days that augmented the research programme.



JMNT Gray

An exact solution for particle size segregation in chute flow

Upon arrival, visitors provided short, introductory overviews of their research that enabled rapid communication among participants. During the course of the programme, J Rice delivered the Rothschild Lecture on *Granular Flows and Earthquake Faulting* and A Acrivos provided the Distinguished Lecture of the Institute for Mathematics and its Applications (IMA) on *Particle Segregation in Rimming Flows of Viscous Suspensions*. In addition, tutorial reviews that focused on their research perspectives were provided by A Acrivos, RP Behringer, S Edwards and EJ Hinch.

Workshops and Focus Days

Flow and Failure of Dense Fluid-Infiltrated Granular Materials

Focus Day, 17 September 2003

Organiser: J Rice

In this one-day meeting, experts on dense, fluid saturated granular systems highlighted the role played by the pore fluid in mobilizing them. An emphasis was placed on the modelling of the saturated granular gouge in an earthquake fault. Here the pressure in the pore fluid and the mobility of the fault is found to be influenced in important ways by the heat generated by frictional sliding. Pore fluid pressure also was shown to be important to the fluidization of debris flow when incorporated into a depth-averaged theory for their flow.

Flow Regimes, Transitions and Segregation in Granular and Particle-Laden Flows

Workshop, 22–26 September 2003

Organisers: JT Jenkins and T Mullin

This workshop exposed beginners and experts to developments in modelling, experiments and computation over the wide range of behaviour exhibited by granular and particle-laden flows. During the course of the workshop, it became clear that non-local constitutive relations were necessary to describe dense, dry, frictional flows and that pore water pressure played an important role in the liquefaction and mobility in many dense, particle-laden flows. Other presentations emphasized the similarities and differences of particle segregation in a variety of dry and fluid-saturated flows. Segregating flows are similar in that they all involve particle fluctuations; they are different in the forces that are exerted between the constituents. The workshop helped to reveal at least some common physical mechanisms present over a range of seemingly diverse phenomena.

S Wygard

Poster session during the workshop 'Flow Regimes, Transitions and Segregation in Granular and Particle-Laden Flows'

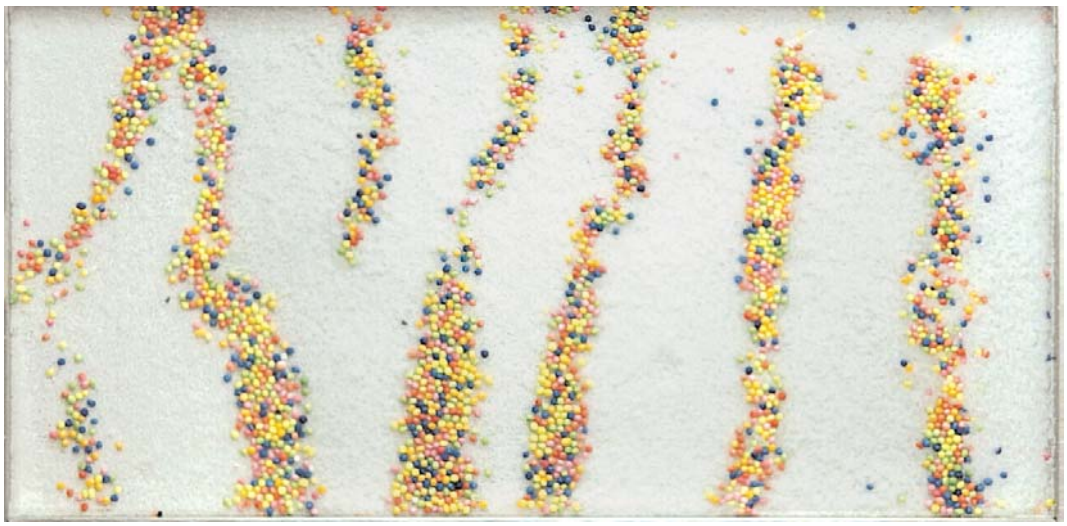
Mathematical Issues in Granular Flows

Focus Day, 20 October 2003

Organisers: DG Schaeffer and M Shearer

Six problems of granular and particle-laden flow were phrased and viewed in a mathematical context. These included the formulation of

T Mullin



A segregation pattern formed when a mixture of polystyrene beads and 'sprinkles' is shaken from side to side

boundary-value problems for steady, fully developed collisional flows, the posing and numerical solution of rate-independent flows in hoppers, the foundations of a general theory for the rate-independent flow of frictional grains, the difficulties encountered in the solution of depth-averaged equations for avalanches, and the incorporation of fluctuations in theories for the deformation of elastic–frictional aggregates.

Geophysical Granular and Particle-Laden Flows

Satellite Workshop at the University of Bristol, 27–31 October 2003

Organisers: JMNT Gray, AJ Hogg and K Hutter

This multidisciplinary meeting proved to be highly successful in providing an opportunity for scientists from very different communities and backgrounds to communicate and exchange ideas with one another on the topic of geophysical granular and particle-laden flows. A broad selection of disciplines was represented, from geologists, Earth scientists, geographers and oceanographers to mathematicians, applied mechanicians and engineers. For many it was the first time that they had met with scientists from other disciplines working on similar and related problems in different contexts. Avalanches on massive scales in very different contexts were seen to involve similar physics. Here, again, the pressure of the interstitial gas or liquid emerged as an important feature of the description. The ability of mixture theories and/or depth-averaged equations to describe the flows was another issue that extended across discipline boundaries. A measure of the stimulating nature of the workshop was the proposal to hold a similar meeting in two years' time.

Computational Aspects of Granular and Particle-Laden Flows

Hewlett-Packard Day, 17 November 2003

Organiser: K Hutter

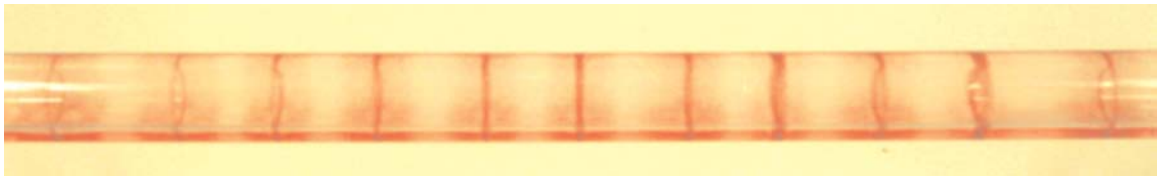
The four presentations dealt with a range of computational techniques that are relevant to granular and particle-laden flows. These are discrete-element simulations of aggregates of individual particles, the integration of the multidimensional equations of a continuum theory, the integration of the reduced equations of a depth-averaged theory, and numerical simulations of particle clustering in a turbulent gas.

A Young Person's Guide to Granular and Particle-Laden Flows

Focus Day, 8 December 2003

Organisers: JMNT Gray and T Mullin

A fresh perspective was placed on granular and particle-laden flows in seven talks given by young



A Acrivos

When a dilute suspension of neutrally buoyant spheres in a very viscous fluid is placed in a partially filled rotating circular cylinder, the particles separate from the liquid and form regular equidistant bands

scientists. The talks included studies of spheres rolling on a viscous film, the splash of a water droplet on a particulate bed, colliding spheres flowing down a rough inclined slope, cellular foams that expand when stretched, transient segregation in a rotating drum, soil liquefaction, and segregation in vibrated beds.

Statics and Dynamics of Systems of Rigid Particles

Focus Day, 10 December 2003

Organiser: K Hutter

The four talks involved computer simulations, theoretical models and the mathematical analysis of rigid, or nearly rigid, systems. Computer simulations illuminated the role played by the simplest measure of the local geometry; simple theories for the yield of rigid disks and the double shearing of nearly rigid disks were outlined; and the mathematical properties of simple solutions for the steady flow over heaps were demonstrated.

Outcome and Achievements

Although the topics that were treated in the workshops and the focus days were diverse, the research programme evolved in a way that led it to concentrate onto a relatively small number of rather clearly defined areas. These were: development of theories for rigid and nearly rigid particles and for dense, dry frictional flows; behaviour of the depth-averaged equations for granular avalanches; description of particle size segregation; modelling of pore pressure in fluid–particle systems; mathematical aspects of soil plasticity theories; and the application of kinetic theory to particle-laden flows.

Efforts were made to understand the generality of theories for a marginally stable packing of rigid particles and their relation to theories for deformable particles. The development of theory for elastic, frictional particles focused on the prediction of the stress relation and the onset of failure (shear bands) from a consideration of the statistical geometry of the particle interactions. Experimental and numerical evidence for correlation lengths much larger than a particle diameter and the success of scalings based on these observations led to attempts to derive a more general theory for dense, dry, frictional flows. The consideration of depth-averaged equations for granular avalanches focused on the degree of complexity of the constitutive relations necessary for a faithful description of the physics. Also, attention was devoted to the construction of solutions to the hyperbolic system of conservation laws that describe avalanche break-up, entrainment and particle size segregation.

Particle size segregation emerged as one of the topics of broad interest in both granular and fluid–particle systems. Segregation in such systems is typically driven by shearing or vibrations. Particle velocity fluctuations play an important and, perhaps, similar role in segregation in all of these systems, but the fluctuations typically result from different mechanisms in different systems. The relationship between the local strength of the fluctuations and the forces driving the system led to an active area of research.

Models for the influence of pore pressure on the evolution of dense particle–fluid systems are required for granular soils, earthquake fault gouges, and dense avalanching flows of debris and mud. In these systems, increases in pore pressure

A powder snow avalanche in the Nepalese Himalaya
(Photo by F Tschirky, courtesy of the Swiss Federal Institute of Snow and Avalanche Research, Davos, Switzerland)

can result in liquefaction and the catastrophic loss of bearing capacity. Related activity concentrated on the mathematical features of soil plasticity. Here the issue was the loss of well-posedness in several formulations and how one could regularize such theories to avoid it. Attempts were made to apply kinetic theory to solid–fluid mixtures as diverse as fluidized beds and viscous suspensions of buoyant particles. There is accumulating evidence that the kinetic theory may provide a paradigm for the understanding of systems of particles that interact within a fluid. Again, a description of the particle velocity fluctuations is seen to be the key to the appropriate description, but the transfer of energy between particles and between particles and the fluid remains to be characterized.

Collaboration between participants took place in small groups. It is anticipated that strong publications from these newly established collaborations will be a hallmark of the programme. This activity has advanced the current understanding of granular and particle-laden flows by providing a forum for interactions between experts with similar and different interests. It has also exposed a large number of researchers to a broad overview of granular and particle-laden flow processes, the results of experiments and numerical simulations, methods of modelling such as mixture theory, kinetic theory and depth-averaging, and the relevant mathematical analysis.

A total of 46 seminars at other UK universities contributed to the increase in interest in the UK in the subject of granular and particle-laden flow. The activities of the programme brought focus to a broad and diverse community of researchers interested in these burgeoning subjects. The programme was particularly successful in attracting young UK researchers to the workshops and focus days.

An agreement has been established with the Royal Society to publish a subset of the contributions to the workshop on *Geophysical Granular and Particle-Laden Flows* as a special Theme Issue of the Philosophical Transactions of the Royal Society of London. Also, the writing of several research monographs was advanced during the programme.

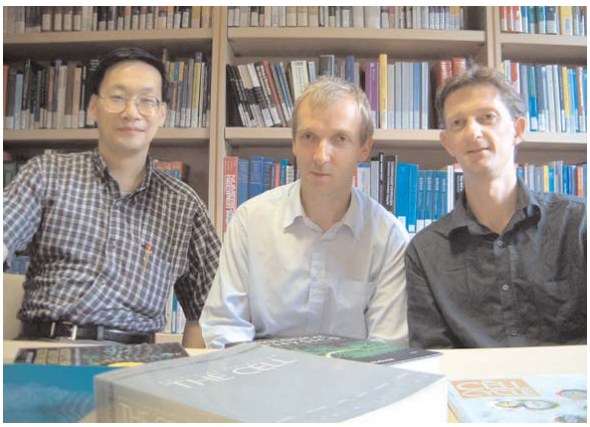
The programme benefited greatly from additional financial support generously provided by a number of sources, including the US National Science Foundation, the US Office of Naval Research and its International Field Office, the London Mathematical Society, the Institute for Mathematics and its Applications and the Natural Environment Research Council.

Statistical Mechanics of Molecular and Cellular Biological Systems

19 January to 9 July 2004

Report from the Organisers: *TAJ Duke (Cambridge), TCB McLeish (Leeds), JE Molloy (York), WCK Poon (Edinburgh), PG Stockley (Leeds), JA Trinick (Leeds)*

S Wilkinson



Left to right: WCK Poon, TCB Mcleish and TAJ Duke

Scientific Background

We are currently witnessing a remarkable period of renewed collaboration between physicists, mathematicians and biologists. Not for the first time are there very good reasons for synergy: the beginnings of molecular biology itself emerged from a previous period in which techniques from physics, and mathematical analysis, demonstrated huge potential to answer biological questions. Famous examples are the application of radio-labelling in Copenhagen in the 1930s and of course the determination of the structure of the "Double Helix" of DNA in Cambridge and London in the 1950s by X-ray diffraction, and the subsequent application to the analysis of protein structures.

This programme arose from the very promising creative tension between the "randomness" of statistical physics and the "specialness" of biology. Two aspects of the growth of these two subjects in the last 20 years created the context for it. In physics, the structure and dynamics of "soft matter" has rapidly become a subject in its own right. Techniques from quantum field theory applied to polymers, membranes, liquid crystals and colloids by Edwards, De Gennes and others reveal a subtle world where gentle forces combine with Brownian motion to create emergent properties such as elasticity, membrane interaction and microphase separation. The field has generated important theoretical tools for studying non-equilibrium and self-organised states, and made contact with increasingly sophisticated experimental data. In biology, it is largely the explosion of accessible data at the level of individual biological molecules and cellular processes that create a ripe moment to provide a context for the two communities to work together. After all, at the cellular level, Biology has chosen the very motifs of polymers and membranes that constitute the raw material for soft matter physics. Furthermore, biomolecules, such as the protein whose structure is illustrated in the figure overleaf, are of the scale that subjects them to continual random Brownian motion – the consequence of heat, and the generating dynamics for the whole approach of "Statistical Mechanics".

However, the very deep methodological differences between physics and biology constitute severe challenges to this hopeful setting. As Fox-Keller has recently pointed out, the very words "theory" and "model" mean very different things to a biologist than they do to a theoretical physicist. The essential step of "coarse-graining" or "renormalization" of a physical system that permits theoretical statistical mechanics (the elasticity of flexible polymers is an emergent property of their connectivity, not of their local chemistry) mystifies a molecular biologist who knows very well that every chemical side-group on a protein, every base-pair in a strand of DNA might *matter*. Yet even the tools used in current molecular biology suggest that sometimes coarse-graining is of use, if not an essential step in understanding. The figure overleaf is a standard representation of protein structure that emphasises not the atomistic detail, but the nature of the "secondary structure" of "alpha-helices" (in cerise) and "beta-sheets" (in yellow).

A 'ribbon' or 'Richardson' representation of the X-ray crystal structure of the lac dimeric protein bound to a short segment of DNA

Recent mathematical theories have begun to shed light on how nature exploits physics in these special molecules. Leibler pioneered physical models of self-assembly and growth of microtubules; Huxley, Jülicher, Duke, Fisher and others simple models for biological molecular motors. Maggs, MacKintosh and Morse have extended coarse-grained models for ordinary polymers to the case of very high local stiffness met with in the case of F-actin and microtubules, while models for the elastic behaviour of DNA at various degrees have been developed by Callaghan, Marko and Siggia, P Nelson, Ou-Yang and others. A rich statistical mechanics for the thermodynamically-driven self-assembly of mis-folded sections of proteins into fibrils and fibres is due to Nyrkova, Semenov and others, and theories of the more finely-tuned self-assembly of viruses has recently been injected with new momentum from Bruinsma, D Nelson and Twarock in the tradition of Caspar and Klug. The organisation and properties of lipid membranes have been addressed by D Nelson, Andelman and others using developments of the celebrated coarse-grained Hamiltonian of Helfrich. The role of electrostatic charge in biomolecular solutions, and its frequently paradoxical effects, has actually stimulated fresh work in physics with a long and current history. Our goal was to stimulate interaction of this new generation of theoretical tools with core scientific programmes in molecular biology, to explore new problems, develop new models, and to move beyond purely reductionist approaches towards an understanding of the systems that the cell's active and passive components constitute.

Cambridge provides an ideal setting for a programme of this highly multidisciplinary type, since such ready expertise in molecular biology was on the doorstep of the Newton Institute. The goal of maintaining a near-constant presence of experimental biologists was increasingly met during the programme, and several local experts were extremely generous with their time.

Structure of the Programme

The overall shape of the programme was designed to allow people interested principally in one of the sub-themes, and unable to participate for the full six months, nevertheless to spend several weeks at the Institute, overlapping with at least one other theme. Long-term participants were able to identify a number of coherent approaches and problems between themes. Visits were guided by a series of four themes that built in logical complexity:

- Single Molecule Biophysics
- Molecular Motors
- Membranes
- Statistical Mechanical Aspects of Gene Signalling

In addition, the programme began with a broad scene-setting week and contained several embedded workshops with satellite meetings in Oxford and Edinburgh. The programme attracted 62 long-stay participants (51 from the UK) and 78 short-stay (45 from the UK). The large overall number of shorter-stay visitors represented the special need for this programme to attract biologists with particular expertise to leave their laboratories and keep the longer-term participants honest! Running experimental work meant that the biologists among the organisers (JE Molloy,

PG Stockley and JA Trinick) were not resident continuously, but were able to visit at strategic times when the relevant theoreticians were resident.

The 6-month duration was especially suited to this type of programme that attempts to engage two very different communities. There was in several cases sufficient time to suggest, advertise and run short focused meetings and workshops not anticipated at the start of the programme, but which arose spontaneously from early collaborations and conversations between participants. A prime example was the Oxford satellite meeting on viral self-assembly. The suggestion arose during the opening conference, funding was sought and obtained from both EPSRC and LMS, an international panel of speakers was arranged, and the meeting was run all before the end of the programme!

Other short meetings of this type included a 3-day workshop on processive molecular motors and another EPSRC-funded 2-day meeting on the protein–protein interactions in the cellular environment.

At the heart of the programme lay the NATO ASI – in this case run very successfully as a satellite meeting in Edinburgh. Organised by WCK Poon and D Andelman, it took the core theme of coarse-graining in soft-matter biological physics into a pedagogical setting: see page 39.

The programme developed another characteristic and very useful activity that we had not foreseen at the start: the 1-day thematic workshop. These were much less formal, and responded to the emergence of interesting questions within the programme themes. One or more biologists would introduce the molecular biology of the topic and present some of the unsolved problems from their perspective. There would then be a plenary discussion, typically provoking a rather different set of questions from the physicists. After lunch, the self-selected group of people keen to develop models and calculations around the topic would then gather around blackboards for the afternoon. Focus workshops of this kind were held on the topics of histone tails (led by A Travers), evolutionary thinking in molecular structural biology (led by S Conway Morris, D Bray and S Laughlin), bacterial chemotaxis (led by D Bray), DNA replication and repair (led by R Laskey and a team of Addenbrookes-based researchers), protein crystallisation (led by WCK Poon, J Doye and A Louis) and unstructured proteins (led by K Dunker).

The Rothschild Visiting Professor was D Frenkel (AMOLF), who contributed at the opening of the programme as well as to the NATO School, and who travelled extensively in the UK. His Rothschild lecture on new sampling techniques in Monte-Carlo simulations was a memorable landmark of the programme.

As well as the core programme support from the Newton Institute, the programme was supported additionally by the BBSRC, the MRC and a further special grant from the EPSRC Life Sciences Interface programme.

Workshops and Conferences

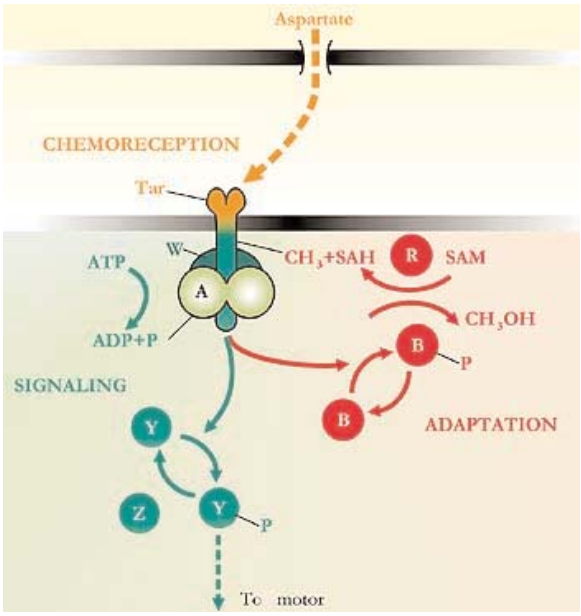
Towards a Predictive Biology?

Workshop, 19–23 January 2004

Organiser: TCB McLeish

The programme started with a remarkable scene-setting conference framed around position-papers given by world leaders in the fields covered by the programme, and covering not only science but also science policy (Julia Goodfellow from BBSRC and Rodney Townsend from the Royal Society of Chemistry) and the undergraduate physics curriculum (P Nelson). In addition, each of the forthcoming themes of the 6-month programme was approached in dedicated sessions. Single-molecule biophysics was presented in the experimental context of magnetic tweezers by V Croquette and theoretically for the protein-folding problem by A Finkelstein and K Dill. Linear motors were discussed experimentally by JA Trinick and theoretically by ME Fisher, and the famous rotational ATP-ase by J Walker. Membrane

D Bray



A coarse-grained representation of the protein-signalling network set into action in the chemotaxis of the bacterium E. Coli

structures such as lipid segregation and curvature were raised by RH Templar and simple models for ion channels by J-P Hansen. Aspects of systems, networks and signalling were presented bioinformatically by JM Thornton and RM Durbin, and using systems modelling by BA Ogunnaike and D Bray, who launched a considerable effort on chemotaxis during the programme. P Nelson nicely summarised the week as a gathering of "people who wanted to meet each other but didn't know it!" The topics spawned the first of several discussions of the mathematical "coarse-graining" of problems in biology as contrasted with soft-matter physics generally, where the spatial levels are less coupled.

Protein Folding

Workshop, 15–19 March 2004

Organisers: TCB McLeish, S Radford and A Fersht

Perhaps the subfield with the longest tradition of a fierce interaction of theory, simulation and experiment is that of the kinetics of protein folding. Two "grand challenge" problems are outstanding:

- How can one predict the folded "tertiary" structure of a protein from its primary sequence of amino acids?
- What are the kinetic pathways and associated rates that characterise the folding dynamics?

The meeting was organised around a structure of two focused sessions each day, introduced for one hour by two contrasting speakers, then followed by a chaired discussion. The nature and investigation of the "transition state ensemble" was a major topic of some controversy, presented by A Fersht, E Paci, E Shackhnovich and D Thirumalai. The new insights made possible by single-molecule mechanical studies were discussed by JM Fernandez and PM Williams. Fast folding and early events, including a discussion of recent "record holders" in folding speed, were presented by WA Eaton and T Kiefhaber, and more extended dynamics on the folding landscape by M Oliveberg and SE Radford. New analytic and computational approaches to the folding problem that attempt to explore the implications of the extremely high effective dimensionality of the search were suggested by D Wales and TCB McLeish. The week was memorably concluded by reflections from CM Dobson, which in a salutary way reinstated the context of protein function around the folding issue. This offered the opportunity to think deeply about the research directions of this field.

Theoretical and Experimental Understandings of Processive Molecular Motors

Discussion Meeting, 23–24 March 2004

Organisers: JE Molloy, TAJ Duke, RA Cross and TCB McLeish

This two-day meeting, part-funded by Hewlett-Packard, addressed our current understanding of the molecular mechanisms of processive motors. The aim was to catalyse a dialogue between experimentalists and theorists interested in this fast-moving scientific area. Processive molecular motors are critical for a wide variety of life functions, and recent advances in experimental techniques and theoretical approaches have

contributed greatly to our understanding of their molecular mechanism; e.g., experimental observations and theory on the stepping mechanism of myosin V. There is a pressing need to define new, experimentally testable models and ideas for how processive motors "walk" along their cellular tracks.

The meeting brought together a large number of UK and also several international experts in the field. The bulk of the delegates gave short 5-minute presentations describing their recent work. This was followed by discussion of each presentation. The meeting then divided into break-out groups which consisted of a balance of Experimentalists and Theorists. These teams addressed a set of detailed questions and reported back in a general session. The meeting ran over two days and allowed sufficient time for informal discussion around the chalk-boards and coffee machines. The meeting was generally accepted to have been successful and to have fulfilled its original aims.

Soft Condensed Matter Physics in Molecular and Cell Biology

NATO ASI & SUSSP 59 Satellite Conference at the University of Edinburgh,
29 March–8 April 2004
Organisers: WCK Poon, D Andelman, F MacKintosh and TCB McLeish

This Advanced Study Institute formed the 59th Scottish Universities Summer School in Physics (SUSSP). Its key objective was to introduce participants to the way 'coarse-graining' (a judicious neglect of details) can solve old biological problems and point to new, fruitful avenues of interdisciplinary investigation. Our method was to examine in some detail the application of recent concepts and techniques from 'soft condensed matter physics' – the study of colloids, polymers and amphiphiles – to the investigation of biomolecules and cells.

The opening lecture by WCK Poon examined how 'coarse-graining' at various levels could give information on the structure and function of a typical globular protein, lysozyme. The rest of the lectures were divided into three groups. First, there was a set of lectures introducing soft condensed matter physics: D Frenkel on colloids, PB Warren on polymers, PD Olmsted on amphiphiles, D Andelman on electrostatic effects and TCB Mcleish on barrier crossing, all emphasizing biological applications.

Three simultaneous views of muscles at work: the actin-myosin system in twin optical traps; the resulting data trace from a single processing myosin motor; and the macroscopic consequence

The second set of lectures dealt with specific topics in biological physics. These ranged from rather detailed treatments of specific biomolecular systems (M Rief on molecular motors and DB Bensimon on DNA and DNA enzymes) through rather generic discussions (such as R Podgornik on electrostatic effects, F MacKintosh on stiff biopolymers, R Elber on protein evolution and JC Smith on protein dynamics) to the movement of whole cells (J-F Joanny).

A final set of lectures was focused on experimental techniques: CF Schmidt on optical tweezers, C Seidel on fluorescence single molecule measurements and SU Egelhaaf on scattering.

In their end-of-workshop Questionnaire, students gave an average of 4.1/5 for the quality of the lectures; in answer to the question on whether they had benefited from the programme as a whole,

they gave the same average score (4.1/5). We also asked students to name the 'scientific highlights' for them. It is interesting that many of them singled out the general introductory lectures to soft condensed matter physics in answer to this question. Most students contributed research posters, two of which were awarded prizes. All of the lectures are now available to the participants in electronic form on the internet.

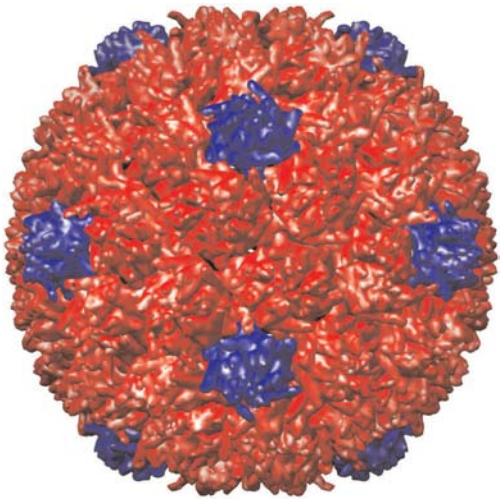
Mathematical Virology

Satellite workshop at the University of Oxford, 14–17 June 2004

Organisers: P Maini, R Twarock, P Stockley and TCB McLeish

The focus of this workshop was on mathematical models for vital stages of the viral life cycle. Particular emphasis was placed on the structure and assembly of viral capsids, i.e., protein shells encapsulating the viral genome, and the packaging of the viral genome inside the capsids. New approaches from symmetry, tiling and elasticity (SR Twarock, P Nelson and RF Bruinsma) contrasted with specific protein-interaction approaches (RW Hendrix, JA King and DI Stuart). The role of dynamics was a central theme (CL Brooks, D Wales and IF Thorpe). The workshop took place at the Mathematical Institute of the University of Oxford with funding from EPSRC, the LMS and the Isaac Newton Institute. It combined a broad spectrum of international participants from mathematics, mathematical physics, biophysics and biology in an inter-disciplinary working environment, and created awareness of open problems and challenges in mathematical virology. The proceedings of the workshop will be published as a special issue of the *Journal for Theoretical Medicine*, edited by TCB McLeish, P Stockley and SR Twarock, as an interdisciplinary state-of-the art account of the field.

C Brookes



Rendition of cryo-electron microscopy images of the HK97 procapsid. 5-fold protein units are shown in red, 6-fold in blue

Protein–Protein Interactions in Vitro and in Vivo

Workshop, 21–23 June 2004

Organisers: J Doye, A Louis, R Sear and M Vendruscolo

This workshop was separately funded by EPSRC, which enabled us to invite 6 international speakers and to pay the expenses of the UK-based participants. In all, 93 attended. Most of the speakers, and those participants who were not members of the host programme, were biologists. The resulting mix of biologists with the physical scientists attending the programme led to real dialogue across the biology–physics divide. The talks dealt with most aspects of protein–protein interactions, from the damaging, such as the interactions causing the formation of amyloid fibrils (CM Dobson and AL Fink), to the exquisitely engineered interactions that allow highly specific protein interactions (JM Thornton, SA Teichmann, J Janin, JL Harden and L Pearl). Also, models for the highly-crowded interactions both *in vitro* and *in vivo* were discussed (AP Minton), as well as their effect on important processes such as protein crystallisation. The ubiquitous question of applicability of coarse-grained models appeared again (SA Deem and TM Truskett). The workshop contributed to three of the four themes of the host programme: protein interactions are central to self-assembly in biological systems, to gene expression, and of course they are what is measured in single-molecule measurements of proteins.

Outcome and Achievements

The programme's central aim was to start radically new approaches to research across biology, mathematics and physics in the four main themes of the programme. A successful outcome from such a goal will be very long-term by its nature, but there were several real achievements made during the six months and there are already signs that the new research collaborations begun are yielding fruit. A dedicated issue of an interdisciplinary journal is in preparation for 2005, as are the proceedings from the workshop *Mathematical Virology*.

One unexpected and pleasing aspect of the programme was the congenial relationship we enjoyed with the parallel programme on *Random Matrix Approaches in Number Theory*. One of our participants (R Sear) actually developed a random matrix approach to protein phase separation in the cell, while another (ME Fisher) spent some time in discussion with the parallel programme on the use of the Yang–Lee theory for ferromagnets.

Another "unorthodox" but creative partnership between Z-C Ou-Yang and P Nelson is leading to the translation (and publication) of Nelson's book *Biological Physics: Energy, Information and Life* into Chinese.

Many collaborations have begun, and some results are already available in detail. At least 30 current preprints or publications contain work done during the programme. We identify some of these outcomes by theme in the following, extending the first category to include aggregates, self-assembly and complex fluids of biomolecules.

Single Molecule Biophysics and Self-assembled Biomolecules

RF Bruinsma began a new formulation of the problem of structure and kinetics of "β-amyloid" self-assembled fibres after discussions with JL Harden, ME Fisher, R Sear and TCB McLeish. JL Harden and R Sear began another novel approach to the problem from an evolutionary standpoint. RH Colby made critical progress on the synovial

Evening entertainment in 'full-swing' during 'Soft Condensed Matter Physics and Molecular and Cell Biology'

fluid system of reversibly aggregated proteins. H Flyvberg, TCB McLeish and BS Khatri sharpened understanding of their complementary work on analysing the Brownian power-spectra from biomolecules in optical tweezers or atomic force microscopes. R Golestanian and TB Liverpool derived a successful theory for the phase behaviour of DNA and actin in the presence of multivalent counterions, and with F Mohammad-Rafiee made a prediction for the under-twisting of condensed actin. S Licher, TB Liverpool and AJ Levine derived a new model for non-linear protein elasticity. Motivated by discussion with M Oliveberg, TCB McLeish found a way to calculate non-native contributions to the curvature of protein folding "chevron plots" from coarse-grained models. WCK Poon and D Dryden solved a long-standing problem in the slow collapse of DNA under flow in the presence of multivalent counterions. R Sear completed a model on protein–protein interactions. RS Twarock completed a model of tubular structures in (papova) virus assembly.

Molecular Motors

H Flyvberg and J Taylor initiated a collaboration on the F0 motor. Collaborations on microscopic models for motor dynamics began between T Golestanian and TB Liverpool, and on the consequences of Brownian searches in landscape models between TCB McLeish and JA Trinick. A Simha, TAJ Duke, A Vilfan and D Andor

developed a model for active travelling waves in the cochlea, where the cilia are coupled hydrodynamically.

Membranes

D Andelman, PD Olmsted and S Komura completed a model for the formation of lipid "rafts" by phase separation within the membrane, now in press. AL Frischknecht completed a calculation on the lateral pressure in a bilayer membrane, prompted by discussions with RH Templar, S Mayor and V Gordon. JL Harden, F MacKintosh and PD Olmsted extended work on budding in membranes. WCK Poon and V Gordon were able to rationalise a large data set on binary lipid vesicles after wide discussion with programme participants in terms of tilted domains.

Gene Regulation and Signalling

D Dryden began a collaboration with JA Trinick to achieve the first high-resolution electron microscopy images of a type I restriction enzyme, and with H Flyvberg derived an analytical model for specific binding of a protein to DNA in the presence of a non-specific binder. ME Fisher and M Howard made progress on proving the existence of a limit cycle in the governing reaction–diffusion equations that M Howard had derived for positioning the mid-cell division plane. D Frenkel continued to develop novel very rapid Monte-Carlo sampling methods and an approach to agent-based modelling. WCK Poon, II Potemkin and TCB McLeish formulated an initial theory for the role of histone tails in control of nucleosome structure, stimulated by discussions of experiments with AA Travers. RJ Hawkins and TCB McLeish completed a calculation of entropy-driven allostery in the *lac* repressor and formulated extensions to this theory to treat the chemotaxis receptor cluster (with D Bray and TAJ Duke), the *met* repressor (with PG Stockley) and the dynein coiled coil (with PJ Knight). M Howard and P ten Wolde developed an approach to pattern formation in Drosophila. BA Ogunnaike completed work on the control loop in DNA damage repair, and began work on coarse-graining differential systems.

Conclusion

So much for the "trees". The success of the programme in regard to detailed progress is clear. Of rather more importance in this case is the "wood". Several long-term participants wrote that their stay had sharpened for them how statistical physics might and might not play a role in biology. Several said that they had come to very useful conclusions about what possible research programmes they were *not* now going to follow! During the six months there was a growing realisation of just how different the approaches of physics and biology are: the questions asked, the definition of a "solved problem", the role of theory, what a "predictive biology" might look like. It was very interesting and gratifying to hear time and again how the visiting biologists found the questions asked of them quite different to those from their own communities, often of course naïve, yet apparently refreshing and stimulating. "We need your approach as well" was often the conclusion of interdisciplinary discussions. There were some huge surprises, such as the neglect of evolutionary thinking and discussion in molecular biology (we were expecting the opposite). This gave rise to a focus day on that topic, and to several new theoretical approaches. Above all, the unpressured time and repeated exposure that the context of the Newton Institute gave to the programme illustrated uniquely how much mutual listening and explaining needs to be done, as well as contributing greatly to the growing realisation that it is going to be worth it.

Random Matrix Approaches in Number Theory

26 January to 16 July 2004

Report from the Organisers: *B Conrey (Palo Alto), P Diaconis (Stanford), F Mezzadri (Bristol), P Sarnak (Princeton), NC Snaith (Bristol)*

S Wilkinson

Left to right: F Mezzadri, B Conrey, P Sarnak and NC Snaith

Background

The connection between random matrix theory and the Riemann zeta function was established in 1973 when Montgomery, who had conjectured the 2-point correlations of the Riemann zeros, and Dyson, who was interested in similar statistics of the eigenvalues of ensembles of unitary matrices, realized that the formulae they had discovered independently were in fact identical in a natural asymptotic limit. Further attempts at the verification of this coincidence of Riemann zero and eigenvalue statistics were then produced from various fronts: overwhelming numerical evidence was afforded by the mammoth computations of Andrew Odlyzko (1989); the heuristic work of Bogomolny and Keating (1995) pointed towards the agreement of not just the 2-point correlation function, but all the n-point statistics as well; and Rudnick and Sarnak (1996) proved that the Riemann zeros and the eigenvalues of this random matrix ensemble have the same n-point statistics in a restricted range.

This programme was designed to draw on the expertise of number theorists, probabilists and physicists to further the recent successes of random matrix theory in predicting results about the Riemann zeta function and other L-functions, thus pointing the way to answering long-standing questions in number theory. Initial results in this direction concerned the mean values of the Riemann zeta function, and with the suggestion of Katz and Sarnak (1999) that by grouping L-functions into families one finds that the distribution of their zeros averaged over the family show random matrix statistics as well, average values of L-functions over families have also been studied using random matrix theory.

The programme has resulted in the formulation of precise and far reaching conjectures about the behaviour of zeta functions and families of zeta functions in terms of their associated (random) matrix symmetry type. These conjectures now have a firm numerical and theoretical basis. Moreover the techniques, developed in part during the programme, to establish some of these conjectures rigorously have proven to be very useful in establishing subconvexity and density theorems for such families of zeta functions. (The latter are often decisive in applications to classical number theoretic and quantum chaos problems.)

Programme Overview

From the beginning we sought to maximise the interaction between participants, especially those coming from different fields. The layout of the Institute was very helpful in this, it being easy to meet over coffee in the central area, but we also organised more structured interaction in the form of two seminars each week, after which all participants were encouraged to socialise over dinner. There was a stress on keeping the seminars accessible to all, so all speakers were asked to include the necessary background material in their talk. On the evidence of the participants' reports it appears that the programme was successful in germinating collaborations that reached beyond the usual pool of researchers' colleagues.

As the programme started during term time and facilities were not available for a large initial workshop, the opening event was a focused working week, which was very productive and set the tone for the rest of the programme. A two-week school was held at the end of March to cover, in a pedagogical manner, the pertinent points of random matrix theory and number theory and the connection between them. Time and again during the remainder of the programme these lectures were referred to as common ground from which to build a mathematical discussion. In May all the current participants relocated to Warwick for a satellite workshop on the areas of probability that are relevant to the programme theme. During the final three weeks of the programme in June and July the number of participants increased, as those who had been unable to get away from university or teaching commitments arrived to take part in the meeting on *Random Matrix Theory and Arithmetic Aspects of Quantum Chaos* and the concluding workshop on *Matrix Ensembles and L-Functions*. The choice of workshops proved to be very popular; all were filled to capacity. They are discussed in more detail below.

Workshops

Ranks of Elliptic Curves and Random Matrix Theory

Clay Mathematics Institute Special Week, 9–13 February 2004

Organisers: B Conrey, D Ellwood, D Farmer, F Mezzadri and NC Snaith

The workshop began with a London Mathematical Society Spitalfields Day, a day which traditionally brings together researchers from all over the UK to listen to expository talks about a field of significant current interest. Random Matrix Theory has proven to be an important tool for modelling the value distribution of families of L-functions. The Birch and Swinnerton-Dyer conjecture relates the value of the L-functions associated with an elliptic curve to the arithmetic structure of the elliptic curve, and this relation serves as the starting point for our investigations.

NC Snaith

Participants at the "Clay Mathematics Institute Special Week"

For the Spitalfields Day talks were given by Bryan Birch and Peter Swinnerton-Dyer, Alice Silverberg, Christophe Delaunay, Michael Rubinstein and Chantal David, introducing topics on elliptic curves and the connection with random matrix theory.

The workshop that followed in the next four days was a little unusual in that the intention was to bring together a group of people to try to understand some very specific problems. Consequently, the schedule of the workshop had very few announced talks. The rest of the time was set aside for discussion sessions, work sessions and talks that could be given as needed or as requested by the thirty-eight participants.

The goals of the week were to better understand the frequency of rank two elliptic curves occurring in a family of quadratic twists of a given elliptic curve, as well as to discuss the occurrence of higher ranks and to find a way to compute twists of higher weight cusp forms. Working groups were formed on the Thursday to attack very specific questions relating to these issues.

The workshop seemed to be unusually successful in that we were able to make inroads in all of our stated goals. In summary, having specific aims in mind, allowing for plenty of discussion time, work time, and unscheduled time that could be planned during the course of the week, seems to have created an opportunity to accomplish these specific goals.

NC Snaith

Michael Berry

Recent Perspectives in Random Matrix Theory and Number Theory

EC Research Training Network School, 29 March–8 April 2004

Organisers: F Mezzadri and NC Snaith

This two-week school, funded by the European Commission Research Training Network "Mathematical Aspects of Quantum Chaos", the Mathematical and Theoretical Physics group of the Institute of Physics and the National Science Foundation, was one of the most important events of the programme.

The workshop was designed with the interdisciplinary nature of this programme in mind. Teaching young researchers in mathematical physics mathematical techniques from random matrix theory and number theory, which are not a natural part of their education, is essential to introduce a new generation of scientists to this field, which is important and rapidly developing but is hampered by the problem that very few researchers are well versed both in number theory and methods in mathematical physics.

There were twelve lecture series, comprising between three and six lectures each an hour long, plus two special lectures by Oriol Bohigas and Michael Berry giving a historical perspective of the subject. The lectures were arranged so as to start from the basics in random matrix theory and number theory separately and to progress to absolutely the most recent work utilising the connection between these two fields.

At the request of the students, a session was held to discuss open problems in the field of a type that might be suitable for a graduate student's thesis project. A volume of proceedings from this school is being created and should prove to be a valuable text for students in this field.

As well as attending lectures over the 11 days of the school, the 97 participants, from professors to graduate students, made new contacts that bridged the usual boundaries of their disciplines. In addition, many of the young researchers participated in later events in the programme, thus putting the knowledge they gained at the school to immediate use.

Random Matrices and Probability

Satellite Conference at the University of Warwick, 18–21 May 2004

Organisers: F Mezzadri, N O'Connell and NC Snaith

This meeting was a satellite workshop held at the University of Warwick and partly sponsored by the London Mathematical Society. It was focused on aspects of random matrices that appear in the theory of probability and on their connections with number theory.

The themes discussed included: Brownian motion and the Riemann zeta function; eigenvalues of non-Hermitian random matrices; universality, sparse random matrices, transition matrices and stochastic unitary matrices; free probability and free stochastic calculus; matrix-valued diffusion and Brownian motion on symmetric spaces; and intertwining relationships in random matrix theory and Markov processes.

About 40 researchers participated in the workshop, half of whom were attending the programme at the Newton Institute. The audience had quite a diverse background and included number theorists, physicists and probabilists. Indeed one of the goals of the meeting was to bring together mathematicians with different areas of

S Wilkinson

Participants at the Euroconference "Matrix Ensembles and L-Functions"

expertise to produce new ideas on how recent developments in random matrix theory can have an impact in number theory. The meeting integrated very well also with the activities in the Department of Mathematics at the University of Warwick and the departmental colloquium was part of the workshop, given by one of the participants, Professor Kurt Johansson.

Random Matrix Theory and Arithmetic Aspects of Quantum Chaos

Euroconference, 28 June–2 July 2004

Organisers: J Marklof, F Mezzadri and Z Rudnick

The main open questions in quantum chaos concern the statistical properties of spectra and eigenfunctions of quantum systems whose classical limit manifests chaotic behaviour. This workshop addressed these problems by focusing on quantum systems in a natural number-theoretical setting, as these are the only models for which rigorous results have been obtained up to now.

The main themes discussed in the meeting concerned: the proof of quantum unique ergodicity; the proof of the existence of scars in quantum cat maps; the analysis of the value distribution of eigenstates on hyperbolic manifolds; the proof of the Berry–Tabor conjecture for spectral two-point statistics for certain classes of integrable systems; the analysis of spectral correlations in pseudo-integrable systems; and heuristic analysis of the spectral form factor for systems which exhibit random matrix correlations.

A successful problem session in which the most important unsolved challenges in the field were discussed was held as part of the conference programme. Approximately 60 researchers, among whom were world leading experts in the subject, attended the workshop.

Matrix Ensembles and L-functions

Euroworkshop, 12–16 July 2004

Organisers: B Conrey, P Sarnak and NC Snaith

As the concluding workshop of the programme one of the goals was to provide an opportunity to relay some of the results accomplished during the programme to a wider interested audience. Perhaps a more important aim, however, was to discuss some of the questions and ideas that arose during the programme but that were still unsolved. For this purpose two discussion sessions were timetabled which lead to very active debates and the tabulation of a list of open problems and the means by which they might be tackled. The workshop was also very important for researchers who were not able to attend the rest of the programme. For those who were not able to leave their home institution for an extended period, this workshop served as an opportunity to find out about progress in this field and also to present their own results to the rest of the community.

NC Snaith

Oriol Bohigas

The main topics discussed were moments and ratios of zeta and L-functions as well as the related question of extreme values of these functions and breaking convexity bounds on the size of L-functions. Also discussed were the correlations of the zeros of L-functions, zeta functions on function fields, computing values of L-functions and applying random matrix theory to elliptic curve L-functions.

Outcomes, Achievements and New Directions

The goal of the programme was to identify important questions in number theory that can be answered using random matrix theory and to discover new areas of interest in the connection between these two subjects.

This was achieved successfully starting from the very first month of the programme. The Special Week in February raised many questions concerning ranks of elliptic curves. This will be a topic that will be pursued in diverse directions long after this programme has ended. As an example of a specific result inspired by this workshop, M Watkins used a combination of random matrix theory and elegant number theory to examine the distribution, amongst residue classes, of integers that can be written as the sum of two cubes of rational numbers. Other new results were the computation of special values of twists of L-functions of weight 4 and 6 forms and a conjecture on the distribution of the derivatives of elliptic curve L-functions and the relative size of various components of the Birch and Swinnerton-Dyer formula for the derivative of these L-functions at the critical point.

Another theme that surfaced early on during the programme was that of function field zeta functions. For these functions the Riemann Hypothesis has long been proved, and in 1999 Katz and Sarnak showed that for families of function field zeta functions the type of random matrix symmetry displayed by the zeros can also be calculated. Discussions throughout the programme indicate that this is an area that deserves more attention from number theorists and random matrix theorists alike.

The flexibility of the Newton Institute allowed a focused week on random polynomials to be organised midway through the programme when links with both random matrix theory and number theory began to interest the participants. This lead to comparisons of the statistics of zeros on the unit circle of random polynomials with those of eigenvalues of random matrices, as well as new results by C Hughes and A Nikeghbali on the clustering round the unit circle of zeros of random polynomials.

The block of uninterrupted research time afforded by the programme has also meant that several long-running collaborations have been brought to a conclusion and prepared for publication, such as the paper on integral moments of L-functions by B Conrey, D Farmer, J Keating, M Rubinstein and NC Snaith and the extension of this to ratios of L-functions by B Conrey, D Farmer and M Zirnbauer.

A development at the end of the programme, resulting from the collaborations of D Farmer, S Gonek and C Hughes, all of whom were present for the entire six months, was a new approach toward the important and controversial question of the maximal order of the Riemann zeta-function

on the critical line. Also, at the final workshop, K Soundararajan spoke on work carried out together with Z Rudnick in which they showed how one may, in the case of discrete families, prove a lower bound of the correct order for the conjectured moments. The result was known for the Riemann zeta function (Titchmarsh) but the discrete family analogue was open until the conference on *Matrix Ensembles and L-Functions*.

The interactions during the programme also pressed home the importance of numerical data in this field where random matrix methods lead to conjectures about number theoretical quantities. Skills in computation will be of great importance in the future, especially to young researchers entering the field, as more and more data is needed to test the sophisticated conjectures generated by random matrix theory.

Several developments were made in various aspects of random matrix theory. J Keating and F Mezzadri discovered a new approach to computing the entropy of entanglement in quantum spin chains using random matrix theory. This established an unexpected connection with conformal field theory and statistical mechanics that led to discussions with the participants of the programme *Statistical Mechanics of Molecular and Cellular Biological Systems* which was running parallel to ours, and in particular with M Fisher. Other aspects of random matrix theory treated during the programme that ended up in ongoing research projects include: the generalization of the Fisher–Hartwig conjecture to all classical compact groups, on which E Basor and P Forrester are currently working; experts on integrable systems and the Riemann–Hilbert problem, among whom are A Its and J Harnad, attended the programme giving substantial contributions; and new approaches to spectral correlations at the edge of the spectra of non-Hermitian random matrices were developed by B Khoruzhenko, F Mezzadri and L Pastur.

In general this programme has been very successful in gaining more acceptance for random matrix theory in number theory, along with more willingness from proponents of the two fields to work together. It has sparked interest in this area amongst young researchers and those at the boundaries of the subject, and it has resulted in renewed vitality and a host of new problems to be worked on.

Finances

Accounts for August 2003 to July 2004 (Institute Year 12)

	2002/2003 Year 11 (13 months)	2003/2004 Year 12
Income		
Grant Income – Revenue	1,003,032	1,032,827
Grant Income – Workshop	226,421	254,307
Trust Fund Income	183,904	131,965
Donations – Revenue	512	21,821
Investment Income	31,525	105,412
General Income	7,661	1,771
Total Income	**1,453,055**	**1,548,103**
Expenditure		
Scientific Salaries	362,158	323,023
Scientific Travel and Subsistence	395,477	446,755
Scientific Workshop Expenditure	181,483	208,749
Other Scientific Costs	22,113	16,478
Staff Costs (Payroll)	348,294	328,195
Staff Costs (Contract and Agency)	21,738	21,333
Housing	(7,239)	43,484
Computing Costs	58,689	39,606
Library Costs	11,459	8,752
Building – Repair and Maintenance	23,494	10,568
University Overheads	15,650	42,122
Consumables	27,370	21,686
Equipment – Capital	41,996	45,373
Equipment – Repair and Maintenance	5,000	4,178
Publicity	6,540	3,205
Recruitment Costs	2,519	3,517
Total Expenditure	**1,516,741**	**1,567,024**
Operating Surplus / (Deficit)	**(63,686)**	**(18,921)**
Transfer (to) / from Reprovision	49,291	
Total Surplus / (Deficit)	**(14,395)**	**(18,921)**

Notes to the Accounts

1. Accounting Period

As explained in the *Annual Report 2002–2003*, the Institute's financial year was amended from 1 July–30 June in previous years to 1 August–31 July, to be in line with the University Finance System. This resulted in the year 2002/2003 being of 13 months' duration.

2. Restatement of Accounts

The figure for Grant Income – Revenue in 2002/2003 has been restated: the costs of the Institute building, which are provided by the University of Cambridge (see note 4 below), are no longer included. The figure for Building – Rent, which appeared as a payment to the University in last year's published accounts, has consequently been removed. The overall Surplus / Deficit is not affected by this restatement.

3. Grant Income – Revenue

This breaks down as follows:

	2002/2003 Year 11	2003/2004 Year 12
EPSRC/PPARC Salaries	314,598	323,641
EPSRC/PPARC Travel and Subsistence	297,743	330,041
Trinity College (Isaac Newton Trust)	100,000	100,000
Hewlett-Packard	115,000	115,000
PF Charitable Trust	19,700	20,965
Le Centre Nationale de la Recherche Scientifique	0	12,617
Leverhulme Trust	79,287	77,502
London Mathematical Society	20,000	20,000
Cambridge Philosophical Society	2,000	2,000
Royal Society	2,314	0
University of Cambridge (Staff)	22,390	31,061
University of Cambridge (Equipment)	30,000	0
Total	**1,003,032**	**1,032,827**

4. University of Cambridge Donation

The University provides the Institute building and covers many of the associated costs, including heating and lighting, free of charge. No figures are quoted in these accounts for this donation. In addition, the University covers the salary of the Deputy Director.

5. Trust Fund Income

This breaks down as follows:

Rothschild – Visiting Professors	28,207	20,870
Rothschild – Director	155,697	111,095
Total	**183,904**	**131,965**

These figures represent drawdowns from the Funds' capital. Income distributions from the Trusts (£105,542 in 2002/2003 and £83,855 in 2003/2004) were also added to the capital.

6. Donations – Revenue

The figure for 2003/2004 comprises revenue received from a variety of sources, including Professor K Hutter for the *Granular and Particle-Laden Flows* programme and the Clay Mathematics Institute.

7. Investment Income
This includes income received from Institute endowments, reprovision accounts and deposits. In 2002/2003, income totalling a further £96,016 was reinvested and added to capital. No reinvestments were made in 2003/2004.

8. Scientific Salaries
This includes stipends paid to EPSRC/PPARC Fellows, Rothschild Visiting Professors, the Hewlett-Packard Senior Fellow, the Director and the Deputy Director.

9. Scientific Travel and Subsistence
This includes expenditure incurred by programme participants, Junior Members and the Hewlett-Packard Senior Fellow.

10. Other Scientific Costs
This includes costs relating to meetings of Institute committees, Institute Correspondents' expenses and the travel expenses of overseas participants who visit other UK institutions to give seminars during their stay (see page 9).

11. Housing
This figure represents the net balance of income and expenditure. While there was a small surplus in 2002/2003, there was a deficit in 2003/2004, mainly due to capital purchases for seven new properties.

12. University Overheads
These figures represent the outcome of negotiations with the School of the Physical Sciences, which has agreed to make a substantial contribution from the two Mathematics Departments and other Departments in the School to the Institute's liabilities.

13. Equipment – Capital
The major costs under this heading in 2003/2004 were for the installation of new audio-visual equipment in the Institute's seminar rooms and the refitting of two administrative offices.

14. Donations in Kind
Sun Microsystems gave the Institute a very generous discount on new computer hardware. Over 4,200 books and journals have been donated to date by a large number of publishers and individual members of the mathematical community.

Cumulative Financial Grants and Donations

SERC/EPSRC/PPARC	£10,574k	over 16 years
Trinity College (Isaac Newton Trust)	£2,510k	over 12 years
NM Rothschild and Sons	£2,083k	over 10 years
European Union	£1,370k	over 14 years
Anonymous Donation	£1,065k	
Hewlett-Packard	£1,065k	over 10 years
Dill Faulkes Foundation	£1,000k	
Leverhulme Trust	£855k	over 12 years
St John's College	£750k	over 5 years
NATO	£728k	over 10 years
University of Cambridge	£573k	over 11 years
Le Centre Nationale de la Recherche Scientifique	£435k	over 10 years
Rosenbaum Foundation	£330k	over 7 years
PF Charitable Trust	£240k	over 3 years
London Mathematical Society	£232k	over 13 years
Clay Mathematics Institute	£160k	
Gonville and Caius College	£100k	
Prudential Corporation plc	£100k	over 4 years
Institute of Physics	£69k	over 12 years
British Meteorological Office	£64k	
Nuffield Foundation	£57k	
TSUNAMI	£40k	
Daiwa Anglo-Japanese Foundation	£36k	over 4 years
American Friends (Hamish Maxwell): $50k	£32k	
American Friends (Anonymous Donation): $50k	£32k	
Emmanuel College	£30k	
Jesus College	£30k	over 6 years
Office of Naval Research	£28k	
British Aerospace	£25k	
Rolls Royce	£25k	
Cambridge Philosophical Society	£25k	over 10 years
NERC	£22k	
Corporate Members (*Financial Mathematics* programme)	£22k	
British Gas	£20k	
DERA	£20k	
Magnox Electric	£20k	
Paul Zucherman Trust	£20k	
Thriplow Trust	£18k	
Schlumberger	£17k	
Bank of England	£15k	
Wellcome Trust	£15k	
Benfield Greig	£10k	
Unilever	£10k	
Applied Probability Trust	£10k	over 3 years