Isaac Newton Institute for Mathematical Sciences

Annual Report
1997 ~ 1998

UNIVERSITY OF CAMBRIDGE

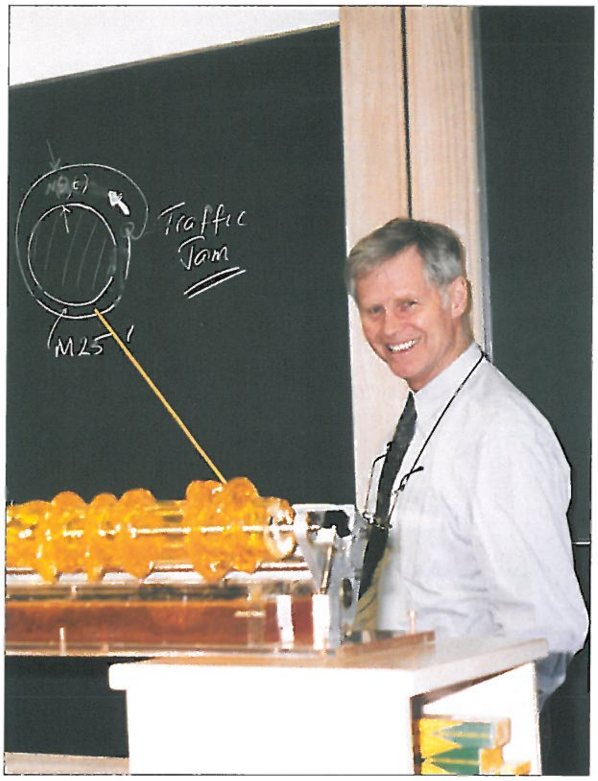
Contents

APPENDICES

Please note that the following statistical information may be obtained on request from the Institute, or from WWW at

http://www.newton.cam.ac.uk/reports/9798/appendices.html

Director's Preface



Professor Keith Moffatt, FRS

Our four programmes this year were associated with the fields of Theoretical Physics (*Disordered Systems and Quantum Chaos*), Computer Science (*Neural Networks and Machine Learning*), Astrophysics (*Dynamics of Astrophysical Discs*), and Pure Mathematics (*Arithmetic Geometry*). These programmes attracted a record participation of more than 1400, a reflection of the exceptional number and vigour of the various workshops held within the programmes. The programme reports on pp18 - 46 of this Annual Report convey their great vitality, and the many new lines of enquiry that have been opened up and explored. The strong national and international participation in these programmes provides continuing evidence of the extremely high reputation of the Newton Institute on the world stage of research in the mathematical sciences.

Our Scientific Steering Committee (SSC) met twice (in October 1997 and April 1998) and selected a number of new programmes covering a wide range of topics in the mathematical sciences (pp13 - 17) which now take us well into the new Millennium. Our strong emphasis on interdisciplinarity continues, the programmes in 1999 involving the application of mathematics in Physics, Astrophysics, Engineering Science and Materials Science. In 2000, the Institute pendulum will swing back towards Pure Mathematics, with the programmes on *Ergodic Theory, Geometric Rigidity and Number Theory* (January - July) and *Singularity Theory* (July - December).

Retiring members of the SSC at 31 December 1997 were Tom Kibble, Jürgen Moser and Terry Wall, and I would like to record my personal thanks to them for their greatly valued service to the Committee and to the Institute. We also said goodbye to Michael Atiyah, who moved to Edinburgh in January 1998, where we wish him a happy (and no doubt mathematically active) 'retirement'. He remains a Senior Fellow of the Institute, as do also Peter Goddard and Peter Swinnerton-Dyer, whose participation in activities of the Institute continues to be a source of wise council and inspiration. We welcome as new members of the SSC: Nigel Hitchin (Oxford), Simon White (Max-Planck-Institut für Astrophysik, Munich), and Don Zagier (Max-Planck-Institut für Mathematik, Bonn).

I am delighted that our collaboration with BRIMS (Hewlett-Packard's Basic Research Institute in the Mathematical Sciences) continues. Strong links have been maintained through Sandu Popescu, our Hewlett-Packard Reader in Quantum Mechanics, as well as through Michael Berry (who serves on our Scientific Steering Committee) and Jon Keating (one of the organisers of our programme on *Disordered Systems and Quantum Chaos*). This collaboration is now set to continue for a second five-year period.

Great news on the fund-raising side was the announcement in May 1998 of the endowment of a new Professorship in the Mathematical Sciences by the Merchant Bank NM Rothschild and Sons, this Professorship to be held (following my own tenure) in conjunction with the Directorship of the Newton Institute. We celebrated this endowment, and also the announcement of a new Victor Rothschild Memorial Fund, at a reception at the Institute on 4 June 1998. A portrait of NM Rothschild now hangs on the mezzanine floor of the Institute; and a photographic portrait of the late Lord (Victor) Rothschild hangs in the Institute Library. This generous benefaction is of the greatest importance for the Institute, providing essential underpinning for its long-term future, and releasing matching funds from the Isaac Newton Trust to provide the nucleus of an endowment fund for the Institute.

Keith Moffatt

30 June 1998

News in Brief

Programmes

During the year July 1997/June 1998, a total of 1479 visitors took part in the Institute's programmes and workshops. There were 20 workshops, over 650 seminars were presented at the Institute, and around 200 papers were produced or are in preparation by participants.

The programmes that took place were:

Disordered Systems and Quantum Chaos
July to December 1997
Organisers: JP Keating (Bristol); DE Khmelnitskii (Cambridge); IV Lerner (Birmingham); P Sarnak (Princeton).

Neural Networks and Machine Learning
July to December 1997
Organisers: CM Bishop (Microsoft/Edinburgh); D Haussler (UCSC); GE Hinton (Toronto); M Niranjan (Cambridge); LG Valiant (Harvard}.

Dynamics of Astrophysical Discs
January to June 1998
Organisers: J Goodman (Princeton); JCB Papaloizou (QMW); JE Pringle (Cambridge); JA Sellwood (Rutgers).

Arithmetic Geometry
January to June 1998
Organisers: J-L Colliot-Thélène (Orsay); J Nekovář (Cambridge); C Soulé (IHES).

Special Appointments

The following 'visiting' appointments were made during the year:

- Gabriella and Paul Rosenbaum Fellows

  Dr Michael Haggerty (William & Mary College, Virginia)
  Disordered Systems and Quantum Chaos

  Dr Thomas Richardson (Washington)
  Neural Networks and Machine Learning

  Dr Charles Gammie (Harvard)
  Dynamics of Astrophysical Discs

  Dr Bjorn Poonen (UCB)
  Arithmetic Geometry

- Institute of Physics Fellow

  Professor Shmuel Fishman (Technion, Haifa)
  Disordered Systems and Quantum Chaos

Fletcher Morgan

Jens Marklof, EPDI Fellow

- European Post-Doctoral Institute Fellow

  Dr Jens Marklof (BRIMS)
  Disordered Systems and Quantum Chaos

- Marie Curie Fellowship

  Dr Klaus Kuennemann (Köln)
  Arithmetic Geometry

Special Events

Peter Swinnerton-Dyer Birthday Celebration
(22 - 23 September 1997)
A special meeting entitled *Diophantine Geometry and Differential Equations* was held to celebrate Sir Peter Swinnerton-Dyer's 70th birthday. Speakers and titles were:

- C Sparrow (Cambridge): *Ordinary Differential Equations: Explosions and Bifurcations*
- N Lloyd (Aberystwyth): *Hilbert's 16th Problem, 97 Years On*
- M Reid (Warwick): *The Cubic Surface Through the Ages*
- R Taylor (Harvard): *Weight One Forms, Congruences and Galois Representations*

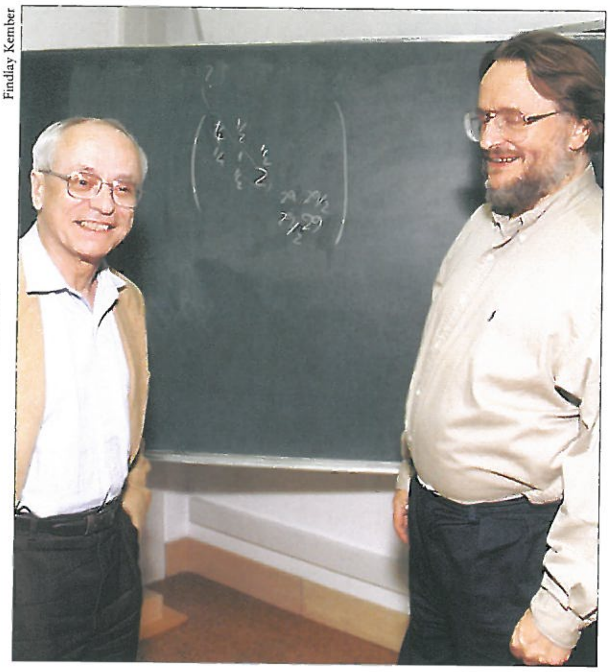
- J-L Colliot-Thélène (Orsay): *Local-to-Global Principles for Varieties Over a Number Field*
- J Nekovář (Cambridge): *Euler Systems and the Conjecture of Birch and Swinnerton-Dyer*
- D Zagier (Max-Planck-Inst): *Diophantine Equations and Differential Equations*

William Oxbury

Back row (left to right): Richard Taylor, Noel Lloyd, Jan Nekovář, Jean-Louis Colliot-Thélène, Miles Reid, Don Zagier. Front row (left to right): Colin Sparrow, Sir Peter Swinnerton-Dyer, Bryan Birch

ConwayFest (16 - 17 April 1998)
A special meeting was held to celebrate John Conway's 60th birthday. Speakers and titles were:

- NJA Sloane (AT&T Labs Research): *Recent Results on Packing Spheres in n-Dimensional Space*
- J-P Serre (Collège de France): *Zeroes of Characters*
- E Berlekamp (Berkeley): *Sums of Nx2 Amazons Positions*
- S Kochen (Princeton): *Geometry, Logic and Quantum Theory*
- B Fischer (Bielefeld): *Remarks on Sporadic Simple Groups*
- RE Borcherds (Cambridge): *Hyperbolic Reflection Groups (after Conway and Allcock)*
- SP Norton (Cambridge), RA Wilson (Birmingham): *Atlas Double Bill*
- L Kauffman (UIC): *Conway's Knots and Their Ramifications*
- JH Conway (Princeton): *The Fifteen Theorem for Quadratic Forms*



Findlay Kember

John Conway (right) with Jean-Pierre Serre at the ConwayFest

Celebration of Rothschild Donation (4 June 1998)
A special meeting was held in celebration of the endowment of the new Rothschild Professorship in Mathematical Sciences, and the inauguration of the Victor Rothschild Memorial Fund.

Professor Sir Martin Rees FRS gave a lecture entitled *Some Cosmic Problems and Matters of Gravity.* A reception was then held, at which Sir Evelyn de Rothschild unveiled a portrait of Nathan Meyer Rothschild, founder of the bank NM Rothschild and Sons. A photographic portrait of the late Lord Victor Rothschild was also donated to the Institute.

Findlay Kember

Keith Moffatt and Emma Rothschild with Sir Evelyn de Rothschild, unveiling the portrait of Nathan Mayer Rothschild

Other Scientific Events

A number of different scientific events took place during this year in addition to the Institute's programmes. These included:

- Special meeting of former participants in the programme *Mathematics of Atmosphere and Ocean Dynamics* held in 1996 (1- 5 December 1997)
- Special meeting on *Biological Mathematics* (18 - 19 December 1997). This was a round table discussion between biologists and mathematicians to define the scope of a future programme of the Institute (*From Individual to Collective Behaviour in Biological Systems,* see p17)
- Meetings to discuss *Soft Condensed Matter* (12 January 1998 and 20 April 1998)

Other Events

Other important events held at the Newton Institute during this year included:

- The University's Alumni Weekend (27 September 1997), for which Professor Christopher M Bishop gave a seminar entitled *Neural Networks: Past, Present and Future*
- A meeting hosted by Sun Microsystems (27 November 1997)
- A celebration both of the Chinese New Year, and of the gift of an embroidered silk from mathematicians of the Railway Institute in Changsha, Hunan Province in China, to Professor David Kendall who in turn donated it to the Institute (28 January 1998)

Findlay Kember

The Chinese silk tapestry given to David Kendall by the mathematicians of the Railway Institute in Changsha, and donated to the Newton Institute

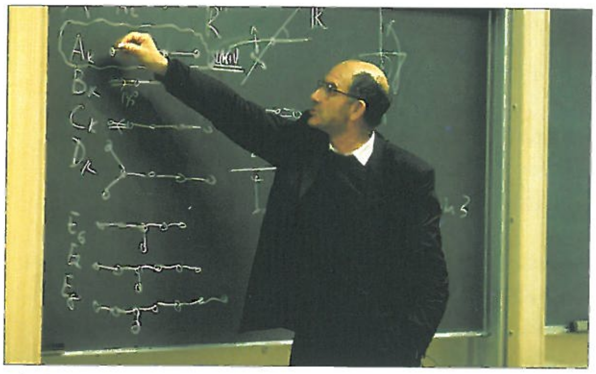
- A visit by EC ministers and Civil Servants (14 February 1998)
- A meeting for a broad selection of UK Heads of Departments of Mathematics, Physics, Statistics and Computer Science at which the work of the Institute was presented, and discussion invited (4 March 1998)
- A meeting for Industrialists (6 March 1998)
- National Science Week, SET 98 (21 March 1998) when the Director gave a general interest lecture entitled *Syrup Rings and Traffic Jams*
- Visit of Deputy Prime Minister of Singapore to invite the support of the Institute in the promotion of a Distinguished Lecture Series in Singapore (March 1998)

Institute Seminars

In addition to seminars held within programmes, we continue to hold a series of Institute seminars, accessible to a general mathematical audience. Institute Seminars given in 1997/98 were as follows:

- 13 October 1997: J Keller (Stanford)
  A Survey of Wave Motion
- 20 October 1997: D Haussler (UCSC)
  Statistical Genome Analysis: Hidden Markov Methods
- 27 October 1997: J Moser (ETH-Zurich)
  Stability in Dynamics, Invariant Sets and the Burgers Equation
- 3 November 1997: CM Bishop (Microsoft/Edinburgh)
  Neural Networks: A Probabilistic Perspective
- 10 November 1997: L Kauffman (Illinois)
  Virtual Knot Theory
- 24 November 1997: J Keating (Bristol)
  Cat Maps - Classical, Quantum and Semiclassical
- 1 December 1997: D Thouless (Washington)
  Topological Quantum Numbers and Precise Measurements
- 19 January 1998: A Newell (Warwick)
  Semiconductor Lasers and Kolmogorov Spectra
- 2 February 1998: S Balbus (Virginia)
  Turbulence in Accretion Disks: Progress and Problems
- 2 March 1998: C Deninger (Munster)
  Analogies Between Number Theory and Dynamical Systems on Foliated Spaces

- 20 April 1998: VI Arnold (Steklov)
  Polymathematics: Symplectisation, Complexification, Mathematical Trinities and All That: Is Mathematics One Science or Several Arts?



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Vladimir Arnold presenting his Institute Seminar

- 4 May 1998: J Heyvaerts (Strasbourg)
  Magnetic Field Interaction with a Turbulent Accretion Disk
- 11 May 1998: WT Gowers (Cambridge)
  Arithmetic Progressions of Length Four
- 18 May 1998: C Soulé (IHES)
  The Arithmetic Riemann-Roch Theorem

European Post Doctoral Institute (EPDI)

The Newton Institute continued to collaborate with IHES (Bures-sur-Yvette) and the Max-Planck-Institut für Mathematik (Bonn) in this initiative, which encourages mobility within Europe of young postdocs in the mathematical sciences. One of the five EPDI Fellows appointed in 1997 participated in the programme *Disordered Systems and Quantum Chaos* (Dr Jens Marklof - see above) and further Fellows were selected from a large field of candidates at meetings held at IHES on 12 January and at MPIM (Bonn) on 30 January 1998.

Honours

The Institute offers its congratulations to the following:

- Professor Geoffrey Hinton (Organiser, *Neural Networks and Machine Learning*)
- Professor Ashoke Sen (Rothschild Professor, July - December 1997)
- Dr John Taylor (Director, Hewlett Packard Laboratories, Bristol)

  Elected to Fellowship of the Royal Society, May 1998

- Professor Keith Moffatt FRS (Director)

  Elected Associé Étranger, Académie des Sciences, Paris, June 1998

  Officier des Palmes Académiques, January 1998

- Professor Peter Goddard FRS (Senior Fellow of the Institute) and Professor David Olive FRS (Organiser, *Non-Perturbative Aspects of Quantum Field Theory*, July-December 1997)

  Awarded the Dirac Medal, 1997

- John Toland (Member of the Scientific Steering Committee)

  Awarded Senior EPSRC Fellowship, June 1997

Centre for Mathematical Sciences

The Cambridge Departments of Pure Mathematics & Mathematical Statistics and Applied Mathematics & Theoretical Physics have been planning for some time to move into new buildings on the field adjacent to the Institute. An intensive Faculty fund-raising campaign (quite independent of the Institute's fund-raising activity) is underway; sufficient funds have been raised to complete the first phase of the building and work has now begun on this. On 4 April 1998 there was a Ground-Breaking Ceremony when Dr Hans Rausing (a major donor) cut the turf for the project. The first phase will be completed early in 2000. The new Physical Sciences and Technology Library will be built as part of a later phase, and is due to be completed between Easter and Summer 2001; this will be fully accessible to members of the Institute.

Findlay Kember

(left to right) Roger Needham, David Crighton, Raymond Lickorish, Peter Goddard, Peter Landshoff and Hans Rausing

Outreach

The Newton Institute has put increasing emphasis on outreach during the past year and will continue to do so. Colin Sparrow continued in the role of Institute Liaison Officer. The Institute's programmes are publicised widely. All information is available on our website (**http://www.newton.cam.ac.uk**) and is regularly updated. We issue frequent mailouts via postal services and email. Lists of visitors are also available on WWW.

Following discussions with LMS, a minimum target of 20% UK (non-Cambridge) participation has been agreed for each programme of the Institute. This target is emphasised in all discussions with Programme Organisers. It has been amply attained in all of the 1997/8 programmes, with the exception of *Arithmetic Geometry*, for which the UK (non-Cambridge) participation was 18%; in compensation there was an exceptionally strong French participation in this programme.

Participants in the Institute's programmes are actively encouraged to visit other UK institutions during their time here. The Newton Institute will pay travel expenses within the UK for such visits.

During 1997/98, over 150 seminars were given outside the Institute by participants. UK universities and other institutions at which these seminars were given include: Aston; Bath; Birmingham; BRIMS (Hewlett-Packard); Bristol; Brunel; British Association for Advanced Sciences (Leeds); Durham; Edinburgh; Equifax; GlaxoWellcome (Stevenage); Hertfordshire; Imperial College, London; Kings College, London; Leeds; Leicester; Liverpool; Loughborough; Manchester; Newcastle; Nottingham; Open; Oxford; Royal Holloway College, London; St Andrews; Sheffield; Southampton; Sussex; University College, London; Warwick; York; Zeneca.

The Director, Deputy Director and Liaison Officer visited several Universities during the year to present the work of the Institute and to explain its procedures. In addition, an important meeting was held at the Newton Institute on 4 March 1998. A selection of about forty Heads of Departments of Mathematics, Physics, Statistics and Computer Sciences from around the UK was invited to attend. This meeting was planned as the first of a series. It began with a presentation of the Institute's work and procedures and continued with an intensive question-and-answer session. The Director also attended both the BMC and BAMC meetings in April to outline the Institute's work, to seek feedback from the UK mathematics community.

In response to these discussions, it has been decided that:

i) short (three-week) summer programmes will be introduced in addition to the standard (six-month and four-month) programmes, with effect from July/August 2000;

ii) organisers of future programmes will be encouraged to consider the possibility of holding at least one of the Programme Workshops at another UK University or Research Centre;

iii) organisers will be encouraged to consider including one weekend meeting in each programme, to improve accessibility to UK University teaching staff.

Hewlett-Packard's Basic Research Institute in the Mathematical Sciences (BRIMS) was founded in 1994 as a partnership with the Isaac Newton Institute. The most visible aspect of this is the Hewlett-Packard Senior Research Fellowship, currently held by Dr Sandu Popescu, who describes his work in the foundations of quantum mechanics and quantum computation below. The strategic value of such a relationship lies in the access it provides to the mathematical science community. The Newton Institute is an attractor in the community's dynamics: almost all mathematicians eventually pass through its doors. It is remarkable among the World's leading mathematical science institutions in the breadth of its programmes: from biology and computer science to the further reaches of pure mathematics. This last year, we organised at the Newton Institute a Discussion Meeting on *Basic Research in Mathematics: Collaboration between Academia and Industry* which brought together representatives from academia, industry and Government. The Institute was an excellent venue for such a gathering, an example in itself of the changing perceptions on which the Discussion focused.

Jeremy Gunawardena
Scientific Director, BRIMS

Report from the Hewlett-Packard Reader in Quantum Mechanics

My main research interest is in the foundations of quantum mechanics, both in its more traditional subjects - measurement theory, topological phases, Bell inequalities, etc - and at present in the very recently developed area of quantum information processing (computation, communication, cryptography).

My research in the past year was centred on a most important aspect of quantum mechanics which plays an essential role in quantum information processing, namely *non-locality*. In a nutshell, objects which interacted in the past remain somehow connected (entangled) to each other, even when separated in space and no longer in interaction.

Probably the most exciting result was that of the first experimental realisation of quantum teleportation. The experiment has been performed at Rome University, by an experimental quantum optics group led by Francesco de Martini, and it is based on an experimental scheme that I proposed. Teleportation (invented by CH Bennett and collaborators) is a way of using non-locality for communicating quantum information. In this process an unknown quantum state is disassembled into, and then reconstructed from, purely classical information and purely non-classical correlations. My proposal, which is a simplification of the original teleportation scheme, avoids unnecessary experimental complications, and enabled this demonstration of the principle of teleportation.

In a related line of research I have been working with Noah Linden, also from the Isaac Newton Institute, in making some first steps towards a general understanding of multi-particle entanglement. This work goes beyond most other works which have focused on correlations between only two quantum particles.

Together with Hoi-Kwong Lo and Tim Spiller of Hewlett-Packard, I edited a book, *Introduction to Quantum Computation and Information*, to appear in October 1998. This book, based on a series of lectures on quantum computation and information that we organised at BRIMS in 1997, is among the first pedagogical books on these subjects.

Sandu Popescu

Young Scientists

Junior Membership

The Junior Membership scheme, designed to involve younger UK researchers in the work of the Institute, has continued to be very successful and numbers are still growing. The total number of Junior Members as at 30 June 1998 was 232. The number who received funding under the Junior Membership scheme in 1997/98 was 42.

Home institutions of Junior Members include: Aberystwyth; Anglia Polytechnic; Aston; Bath; Birkbeck College, London; Birmingham; Bolton Institute; Bradford; Bristol; Brunel; BT Research Labs; Cambridge; Cardiff; Chester; City; Cranfield; De Montfort; Durham; Edinburgh; Exeter; GEC-Marconi Research Centre; Glasgow; Glasgow Caledonian; Goldsmiths College, London; Heriot-Watt; Hertfordshire; Hull; Imperial College, London; Keele; Kent; King's College, London; Kingston; Lancaster; Leeds Metropolitan; Leicester; Liverpool; London School of Economics; Loughborough; Manchester; Napier; Natural History Museum; Newcastle; Northumbria; Nottingham; Open University; Oxford; Paisley; Portsmouth; Queen Mary and Westfield College, London; Reading; Robert Gordon; Royal Holloway and Bedford New College, London; Schlumberger Cambridge Research; Sheffield; Southampton; Sowerby Research Centre; Stirling; Strathclyde; Sussex; Swansea; Teesside; UMIST; University College, London; Warwick; York.

Instructional Conferences for Young Scientists

Within the four programmes, the following conferences were aimed particularly at graduate students and young postdocs:

NATO Advanced Study Institutes:

- Supersymmetry and Trace Formulae: Chaos and Disorder (8 - 20 September 1997)
- Generalisation in Neural Networks and Machine Learning (4 - 15 August 1997)

Summer Schools (EC Human Capital and Mobility Scheme):

- Disordered Systems and Quantum Chaos (28 July - 1 August 1997)
- Probabilistic Graphical Models (1 - 5 September 1997)
- Astrophysical Discs (22 - 26 June 1998)
- Arithmetic Geometry:
  Part I: Instructional Conference (23 - 28 March 1998)
  Part II: Rational Points (30 March - 3 April 1998)

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Young scientists at the EC Summer School on Astrophysical Discs

Spitalfields Day (London Mathematical Society):

- Zeta Functions and Spectra (28 November 1997)

Cambridge Philosophical Society Bursary Awards

The Cambridge Philosophical Society renewed its grant to the Newton Institute at an increased level, so that we were able to offer twice as many of these bursaries for young people as in previous years. The following were recipients in 1997/98:

- *Disordered Systems and Quantum Chaos*
  Dr CJ Howls (Brunel)
  Mr F Mezzadri (Bristol)
  Dr T Monteiro (University College, London)

- *Neural Networks and Machine Learning*
  Dr M Tipping (Aston)

Findlay Kember

Michael Tipping

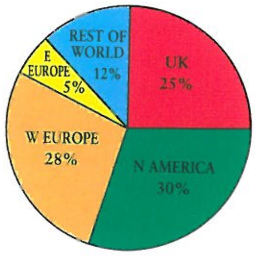
- *Disordered Systems and Quantum Chaos Dynamics of Astrophysical Discs*
  Mr J Larwood (QMW)
  Ms V Agapitou (QMW)

- *Arithmetic Geometry*
  Dr E Frossard (Köln)
  Dr R Rabi (ETHZ)

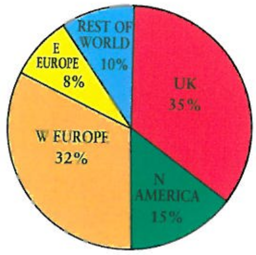
Programme Participation

A total of 1479 visitors was recorded for 1997/98, an increase of 418 on the previous year. This included 237 long-stay participants, each staying between two weeks and six months (seven weeks on average) and 362 short-stay participants who stayed for two weeks or less. Within the four programmes there were 20 workshops in total, which were periods of intense activity on specialised topics, and these attracted an additional 717 visitors to the Institute. In addition, 163 visitors were registered as taking part in the special events held outside the programmes (see pp3 - 6). Many others attended occasionally for lectures, workshops or Institute seminars. In particular, the Director's talk on *Syrup Rings and Traffic Jams*, given as part of SET98 and aimed at young people, filled the seminar room (which holds 120 people) to overflowing.

The pie-charts below show the percentages of long-stay and short-stay participants for 1997/98 broken down by country of residence:



Countries of residence of long-stay participants



Countries of residence of short-stay participants

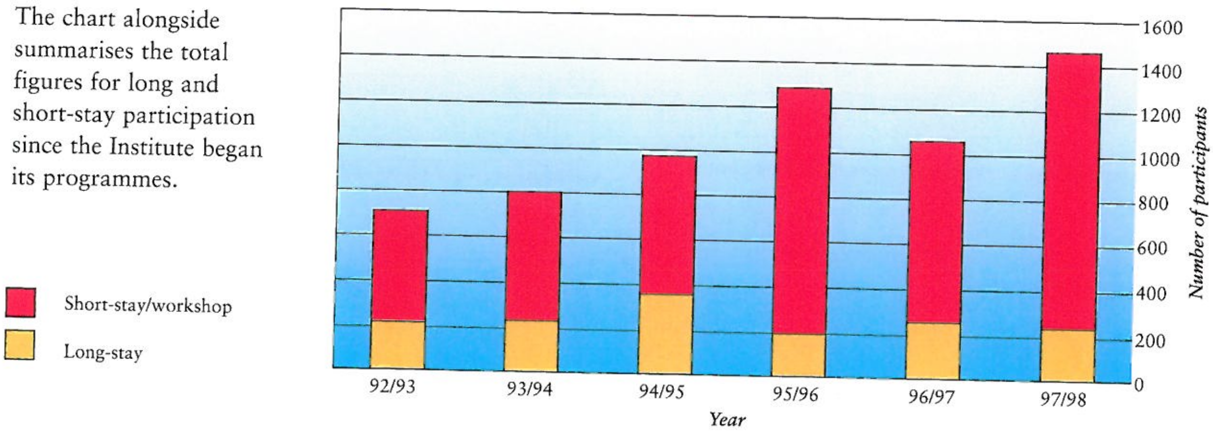
In addition to the workshops, which serve to widen UK participation in the programmes, the programme organisers are encouraged to organise more informal special days, short meetings or intensive lecture series which can attract daily or short-term visitors, so further opening the activities of the Institute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

The statistics for the 1997/98 programmes are given in the following table:

Programme	*Long-Stay Participants*	*Average long stay (days)*	*Short-stay participants*	*Average short-stay (days)*
Disordered Systems and Quantum Chaos	66	46	69	11
Neural Networks and Machine Learning	63	40	121	10
Dynamics of Astrophysical Discs	39	73	52	7
Arithmetic Geometry	69	56	120	7

Summary of long and short-stay participation

The chart alongside summarises the total figures for long and short-stay participation since the Institute began its programmes.



Institute Publications

Newton Institute Papers and Preprints

The complete list of papers produced or in preparation during 1997/98 is given in Appendix F, available on request from the Institute or via WWW at

http://www.newton.cam.ac.uk/reports/9798/appendices.html

Some of these are available in the Institute's Preprint Series, which was re-launched in 1998 with the purpose of providing wider and more immediate dissemination of results from Newton Institute programmes. Participants are encouraged to submit papers to this series. A Web page giving details of Newton Institute Preprints is now available at

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

Books arising from Newton Institute Programmes

The following titles were published during the year 1997/98:

Pierre van Baal (Ed)
Confinement, Duality and Nonperturbative Aspects of QCD
Plenum Press, 1998, £112.95 (hbk)
NATO ASI Series B: Physics, 368; x +550pp

Michael AH Dempster and Stanley R Pliska (Eds)
Mathematics of Derivative Securities
Cambridge University Press, 1997, £55.00 (hbk)
Publications of the Newton Institute, 15; xvii + 582pp

Andrew D Gordon and Andrew M Pitts (Eds)
Higher Order Operational Techniques in Semantics
Cambridge University Press, 1998, £40.00
Publications of the Newton Institute, 12; vii + 390pp

J Gunawardena (Ed)
Idempotency
Cambridge University Press, 1998, £55.00 (hbk)
Publications of the Newton Institute, 11; xii + 443pp

Tom McLeish (Ed)
Theoretical Challenges in the Dynamics of Complex Fluids
Kluwer Academic Publishers, 1997, £99.00 (hbk)
NATO ASI Series E: Applied Sciences, 339; ix + 338pp

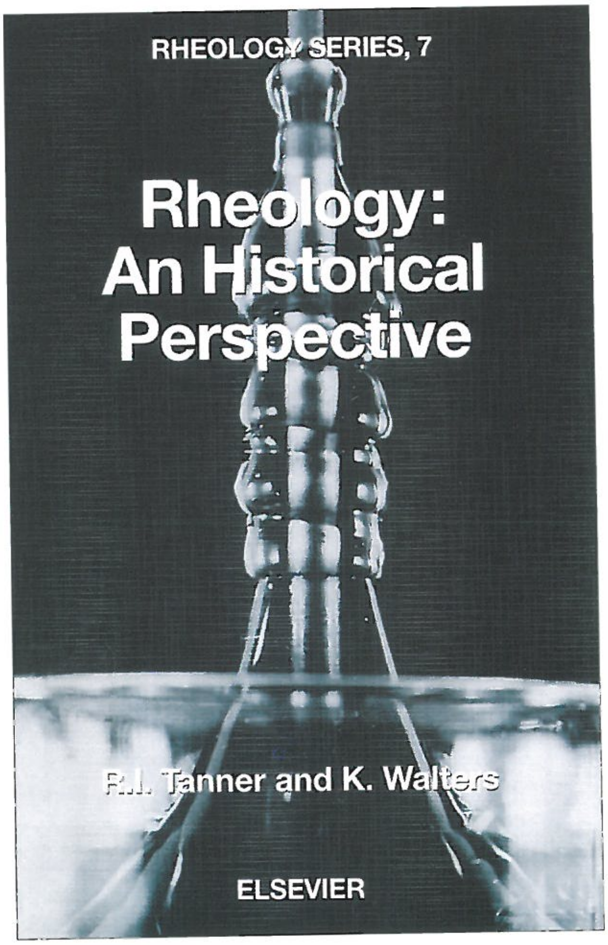
RI Tanner and K Walters
Rheology: An Historical Perspective
Elsevier, 1998, £118.01
Rheology Series, 7; xi + 255pp

A complete list of books published as a result of Newton Institute programmes is available at

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

The Nature of Space and Time by Stephen Hawking and Roger Penrose (*The Isaac Newton Institute Series of Lectures*, Princeton University Press 1996, £16.95 hbk) continues to sell steadily; a total of 28,574 copies have been sold since publication.

Simon Singh's book *Fermat's Last Theorem* (Fourth Estate 1997, £12.99 hbk), which gives an account of the work of Andrew Wiles, including the announcement of his proof at the Institute in 1993, was shortlisted for the 1998 General Prize of the Rhône-Poulenc Prizes for Science books.



Scientific Planning and Future Programmes

Scientific Steering Committee

The members of the committee as at 30 June 1998 were:

Professor Sir Christopher Zeeman FRS (Chairman)	Oxford
Professor HK Moffatt FRS (Secretary and Director)	Newton Institute
Professor Sir Michael Berry FRS	Bristol
Professor J-M Bismut	Orsay
Professor ME Cates	Edinburgh
Professor SK Donaldson FRS	Stanford/Imperial
Professor N Hitchin FRS	Oxford
Professor AF Newell	Warwick
Professor BD Ripley	Oxford
Professor AFM Smith	Imperial
Professor JF Toland	Bath
Professor S White FRS	Munich
Professor D Zagier	Bonn

During this year Professor TWB Kibble FRS (Imperial), Professor J Moser (ETH-Zurich) and Professor CTC Wall FRS (Liverpool) also served (until 31 December 1997) as members of the committee.

The Scientific Steering Committee met twice during 1997/98, on 27 October 1997 and 14 April 1998. Others who attended included Professor AJ Macintyre FRS (Oxford - in place of Professor Donaldson, October meeting); Professor CM Elliott (Sussex - in place of Professor Donaldson, April meeting); Professor D Hand (Open University - in place of Professor Smith, April meeting).

The Scientific Steering Committee meets twice a year in April and October to assess proposals and to advise the Director on which to accept. Except for the Director himself, all the members at present come from outside Cambridge; they represent the whole of the UK mathematical community, and ensure that the Newton Institute is indeed a national institute.

Besides selecting future programmes the Steering Committee also receives reports on past programmes, and spends some time discussing the future policy of the Institute. To ensure a wide coverage of all branches of mathematics, and to maintain a balance between the different branches, the Committee itself sometimes stimulates new proposals. About half the successful programmes are those it has initiated, and the other half come from spontaneous applications. When the Committee wants to initiate a programme in a particular field it asks one of its members to approach a potential programme director in that field and persuade him or her to begin contacting key people throughout the world. The first formal proposal may be submitted some years ahead of the programme itself. It is then refined by a delicate multilateral process of dialogue and negotiation between the referees, the Steering Committee, the officers of the Institute, and the programme directors (including the additional co-directors and key programme participants whom the Steering Committee may have added to the programme on the advice of the referees). Referees often enthusiastically upgrade their assessment when their initial criticisms and recommendations have been met. Finally a programme is accepted only after strict competition with other potential programmes, and usually about two years ahead. Due to the wide coverage and the large numbers of applications only about one in three can be accepted, which means that several excellent proposals regrettably have to be declined.

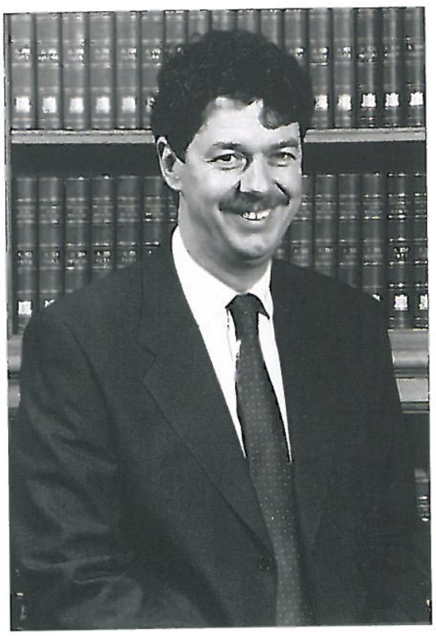
In response to the EPSRC Review Panel Report (February 1998) the Steering Committee is encouraging a greater collaboration with other mathematical bodies, a greater outreach activity with other Universities, a greater flexibility in types of programme, a greater response to the needs of the community, and a greater emphasis upon younger mathematicians.

This year I shall be retiring from the Chairmanship of the Steering Committee and very properly handing it over to a younger pair of hands. Not without some nostalgia, for I have been Chairman since the Institute was founded - indeed I recall that a first planning meeting was actually held in my study in Oxford! Michael Atiyah was still in Oxford at the time, and by a vote of two to one we insisted that Peter Goddard should come over from Cambridge. It has been an exciting experience for me, and a great privilege, and I wish the Institute well for the future.

Christopher Zeeman
Chairman

New Members

Nigel Hitchin
Nigel Hitchin is Savilian Professor of Geometry at Oxford University. His academic career began at Oxford in the late 1960s. In the early 1970s he moved to Princeton and the Courant Institute, before returning to Oxford in 1974. He remained at Oxford until he was elected Professor of Mathematics at the University of Warwick in 1990. Nigel Hitchin was elected Fellow of the Royal Society in 1991. In 1994 he moved to the University of Cambridge where he was Rouse Ball Professor of Mathematics and a Professorial Fellow of Gonville and Caius College, before returning to Oxford in 1997. His research interests are in differential and algebraic geometry and its relationship with the equations of mathematical physics. Current projects include the areas of hyperkähler geometry, special Lagrangian geometry and mirror symmetry, geometric solutions of Painlevé equations, and magnetic monopoles.



Simon White
After graduating in Applied Mathematics from Cambridge, Simon White obtained research degrees in astronomy from Toronto (1974) and Cambridge (1977). This led to a lifelong interest in the origin and structure of galaxies and galaxy clusters, and in the nature of the unseen dark matter which apparently dominates the mass budget of the Universe. Periods of postdoctoral study in Berkeley, Virginia, Paris and Cambridge led to academic staff positions successively at the University of California at Berkeley, the University of Arizona, and Cambridge University. Since 1994 Simon White is Managing Director of the Max-Planck-Institut für Astrophysik in Garching bei München, Germany. He is best known for establishing numerical simulations as a research tool for comparing cosmological theory with astronomical observation, and his work over the last two decades has played a significant role in shaping the current picture of how galaxies form. In 1997 he was elected to the Fellowship of the Royal Society.

Don Zagier
Don Zagier is a scientific member and director of the Max-Planck-Institut für Mathematik in Bonn (MPIM) and also a professor at the University of Utrecht. After graduating in 1968 from MIT with BScs in Mathematics and Physics, he obtained a DPhil from Oxford (1972) and Habilitation from Bonn (1975). He was Professor of Number Theory at the University of Maryland from 1979 to 1990, and also held the Chair of Functional Analysis at Kyushu University, Japan, in 1990/91 and 92/93. Distinctions include: Carus Medal and Prize (1983), Frank Nelson Cole Prize (1987), Prix Elie Cartan (1996); member of the Hamburg Mathematical Society (honorary), the Royal Netherlands Academy (foreign), and the Academia Europaea. Don Zagier's research interests are in number theory (especially Diophantine equations, modular forms, and elliptic curves), moduli spaces, differential topology, algebraic geometry and combinatorics.

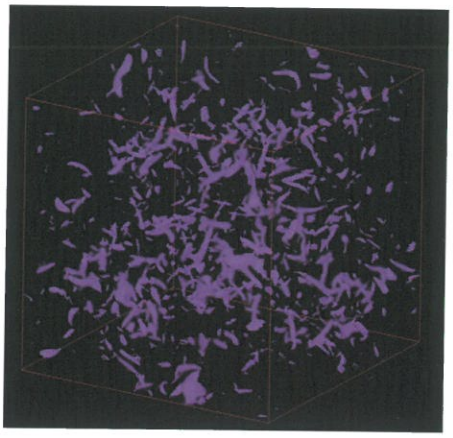
Future Programmes

The following programmes have been selected by the Institute's Scientific Steering Committee:

Biomolecular Function and Evolution in the Context of the Genome Project
July to December 1998
Organisers: P Donnelly (Oxford), W Fitch (Irvine), N Goldman (Cambridge)
There is a long and productive history of interplay between genetics on the one hand and mathematics and statistics on the other. The "molecular revolution" over the last 15 years, and in particular the impetus of genome projects, has transformed the field to one with an abundance of data and a paucity of relevant

mathematical models and techniques. By 1998 the maturation of genome projects will make data on DNA, proteins, gene duplications and gene arrangements on the chromosomes widely available. As a consequence of recent advances in computational statistics, vast improvements in the quality of statistical analyses of these data are possible. They will have a profound impact on the practice of biological research, and, ultimately, medical diagnostics and preventive medicine. The driving force of the present programme is the opportunity offered by genome sequence research to understand biomolecular function and evolution at a much more complete level than hitherto possible and to sustain recent progress in a number of relevant mathematical areas. Problems in analysing the flood of molecular genetic sequences and structures raise a range of challenging biomathematical research topics. This inter-disciplinary programme will bring together mathematicians and computer scientists working on subjects such as probabilistic modelling, stochastic processes, geometry, statistical data analysis, computational complexity, neural networks, genetic algorithms and expert systems; and molecular biologists working in medical and biological fields.

Nonlinear and Nonstationary Signal Processing
July to December 1998
Organisers: WJ Fitzgerald (Cambridge), RL Smith (N Carolina), A Walden (Imperial), PC Young (Lancaster)
The classical theory of signal processing is based on models which are stationary, linear and in many cases also assume that signals have Gaussian amplitude distributions. In recent years there has been a rapid growth in the applications of signal processing in many modern areas of engineering, communications and computing, as well as in financial time series, macro-economics, the environmental and biological sciences, physiology, etc; parallel advances in the theory have introduced many new models and methods. Among these are nonlinear autoregressive and state-space models; models with time-varying or state-dependent coefficients as representations of nonstationary and nonlinear series; adaptive methods of forecasting, interpolation and smoothing; linear non-Gaussian methods, and methods derived from the theory of dynamical systems. The purpose of this programme is to bring together statisticians, engineers and other researchers who use signal processing methodology to develop a general framework to unify existing methods, and to identify areas which may benefit from the application of methods developed for other purposes, or where new methodology is required.



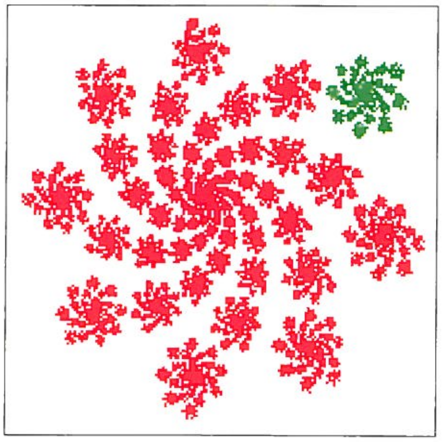
An isovorticity plot of a decaying simulation

Turbulence
January to July 1999
Organisers: GF Hewitt (Imperial), PA Monkewitz (Lausanne), N Sandham (QMW), JC Vassilicos (Cambridge)
Prediction and control of turbulent fluid flow is a scientific problem with immense practical importance. Turbulence is characterised by a large number of weakly correlated motions interacting on a wide range of length- and time-scales which appears disordered and chaotic. However, it also contains organised flow features such as shear layers and long-lived vortex tubes and vortices. Fundamentally different approaches ensue from stressing either the space-filling disorder or the localised order in the flow. A major limitation on the accuracy of prediction of fluid flow in industrial applications is the relative inaccuracy of the turbulence models used in the calculations. This programme will bring together turbulence experts from different communities (mathematical sciences, fundamental fluid mechanics and turbulence modelling) to explain their different approaches and to develop new understanding of both practical and fundamental problems. The objective of the programme will be to determine the extent to which different properties of turbulence may be considered universal. Topics that will help elucidate this question and will be given special attention are transition and control, coherent structures, the relations between geometry, structures, dynamics and statistics, intermittency in turbulence and other dynamical systems, and the mathematical and numerical properties of closure models.

Mathematics and Applications of Fractals
January to April 1999
Organisers: RC Ball (Warwick), KJ Falconer (St Andrews)
This programme is concerned with topical aspects of the mathematics and applications of fractals. Our major aims are to encourage interaction between

mathematicians and scientists with different approaches and viewpoints, to increase the awareness of scientists of the mathematics that is already available, and to focus the attention of mathematicians on areas where further theoretical development is needed. In particular it is hoped to emphasise the following areas: problems of a 'dynamic' nature relating to physical problems, such as diffusions and PDEs on fractals or domains with fractal boundary; multifractal theory and its applications; geometric measure and integration theory, especially recent techniques such as tangent measures; characterisation and measurement of fractals, including alternatives to dimension (eg lacunarity); the identification of mathematically based protocols to identify that a structure is fractal, along with how the mathematical theory 'in the limit' relates to finite scales; and fractal aspects of the distribution of galaxies.

A self-similar fractal spiral of dimension 1.47



Complexity, Computation and the Physics of Information
May to August 1999
Organisers: A Albrecht (UC Davies), P Knight (Imperial), RM Solovay (Berkeley), W Zurek (LANL)
The study of information is linked to a wide range of interdisciplinary research which is defining new frontiers in physics and mathematics. Mathematical notions such as "algorithmic entropy" (or "algorithmic complexity") are central to the fundamental problem of constructing rigorous definitions of entropy and information, while the importance of these concepts to key physical processes (including quantum cosmology, the arrow of time, exotic quantum systems and signal transmission) attracts the attention of theoretical and experimental physicists. An exciting application is that of "quantum computation", which defines challenging problems in mathematics, materials physics, and computer science. The programme will bring together members of all the relevant scientific communities to focus on the physics, mathematics and applications of information and entropy.

Structure Formation in the Universe
July to December 1999
Organisers: VA Rubakov (Institute for Nuclear Research, Moscow), PJ Steinhardt (Pennsylvania), NG Turok (Cambridge)
Understanding how structure emerged in the universe provides one of today's great scientific challenges. Huge quantities of new astronomical data, including maps of the cosmic microwave sky fluctuations and of the distribution of galaxies, are providing stringent constraints on possible theories. At the same time, the results of new particle physics experiments are beginning to imply very strong constraints on the possible nature of the dark matter. The two structure formation theories investigated in most detail so far involve quantum fluctuations generated during inflation, and cosmic defects produced at symmetry breaking phase transitions. Both theories involve physics beyond the standard model, and if either is proven correct, there will be important implications for high energy theory.

The programme will begin with discussions of the latest observational data, including the statistical techniques needed to analyse the new data sets, with the aim of fitting the observations together in a coherent framework. Extensions and variants of current theories, as well as entirely novel approaches will then be considered. During the programme, fundamental questions regarding the big bang and inflationary theory will be addressed, as well as connections to string theory and quantum gravity.

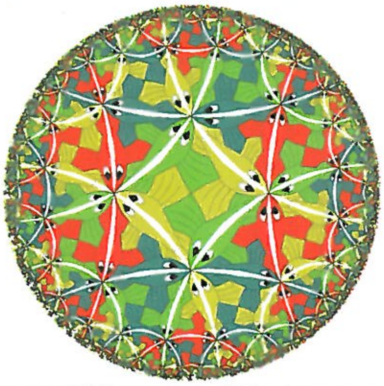
Mathematical Developments in Solid Mechanics and Materials Science
September to December 1999
Organisers: K Bhattacharya (Caltech), P Suquet (Marseille), JR Willis (Cambridge)
There is great current interest in how the microscopic structure of a solid material influences its macroscopic response to stress. Conversely, the application of stress can influence microstructure. Microscopic damage may occur, leading ultimately to the formation of large cracks and structural failure. Phase transformations occur in some materials, creating structures at various length scales which evolve with stress.
The challenge, both for mathematics and physical modelling, is to comprehend relationships between models at different length scales. This has led already to a well-developed theory of "homogenisation" when the scales are widely separated, and has both exploited and stimulated advances in the calculus of variations. When the scales are separated but still comparable, there is a need for a micromechanical rationale for

including scale effects in macroscopic models. The phenomena may be unstable, at least at the microscopic level, and, even if stable, may admit multiple equilibria. Study of the kinetics of the processes is a key requirement, making demands both for modelling and for the analysis of partial differential equations. In particular, the (possibly hierarchical) development of large-scale patterns is an open problem.

The main focus of the programme will be on microstructure formation and evolution, as related to phase transformations, damage development and fracture. Each subject has its own group of specialists (in various mixes, mathematicians, physicists, engineers, materials scientists). There are already overlaps, both between subjects and disciplines, and it is intended that the programme will exploit and extend these, to common advantage.

Ergodic Theory, Geometric Rigidity and Number Theory
January to June 2000
Organisers: A Katok (Penn State), G Margulis (Yale), M Pollicott (Manchester)
The central scientific theme of this programme is the recent development of applications of ergodic theory to other areas of mathematics. In particular, the connections with geometry, group actions and rigidity, and number theory.

The potential of ergodic theory as a tool in number theory was revealed by Furstenberg's proof of Szemerédi's theorem on arithmetic progressions. Foremost amongst the recent contributions to number theory is the solution of the Oppenheim Conjecture, a problem on quadratic forms which had been open since 1929, and the Baker-Spindzuk conjectures in the metric theory of diophantine approximations. Of equal importance is the role of ergodic theory in geometry and the rigidity of actions. The seminal result in this direction is the Mostow rigidity theorem. In recent years there have been diverse results, including rigidity results for higher rank abelian groups, and results on the classification of geodesic flows on manifolds of non-positive curvature.



This is a quickly evolving area of research. The programme will explore these, and other, emerging applications of ergodic theory. It will bring together both national and international experts in ergodic theory and related disciplines, as well as others from the wider UK mathematical community.

Strongly Correlated Electron Systems
January to July 2000
Organisers: DM Edwards (Imperial), AC Hewson (Imperial), PB Littlewood (Cambridge), A Tsvelik (Oxford)
The effects of strong inter-electron interactions give rise to a remarkable range of anomalous behaviour in condensed matter systems, producing phenomena as varied as metal-insulator transitions, the fractional quantum Hall effect, high temperature superconductivity, and heavy fermion metals, insulators and magnets. The high temperature superconductors may even herald a breakdown of the fundamental Fermi-liquid theory of metals.

Although many theoretical models have been put forward as a basis for understanding these systems, new mathematical techniques are required to provide results in the physically appropriate strong interaction regimes where many-body perturbation techniques are not applicable. In recent years non-perturbative methods have been developed and applied with great success to one-dimensional and impurity models, and these have led to an understanding of the breakdown of Fermi liquid behaviour in one dimension.

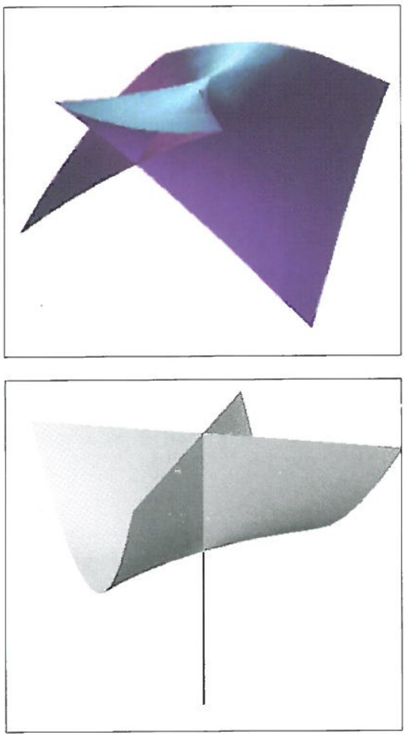
The aim of this programme is to develop many-body approaches which can be applied to higher dimensional systems, and to remaining problems in one dimension such as transport, by bringing together experts from a wide range of mathematical approaches. Links with the experimental community in this field will be maintained, particularly through workshops and seminars.

Singularity Theory
July to December 2000
Organisers: VI Arnold (Moscow and Paris IX), JW Bruce (Liverpool), D Siersma (Utrecht)
Singularities arise naturally in a huge number of different areas of mathematics and science. As a consequence singularity theory lies at the crossroads of the paths connecting the most important areas of applications of mathematics with its most abstract

parts. For example, it connects the investigation of optical caustics with simple Lie algebras and regular polyhedra theory, while also relating hyperbolic PDE wavefronts to knot theory and the theory of the shape of solids to commutative algebra.

The main goal in most problems of singularity theory is to understand the dependence of some objects (from analysis, geometry, physics or elsewhere) on parameters. For generic points in the parameter space their exact values influence only the quantitative aspects of the phenomena, their qualitative, topological features remaining stable under small changes of parameter values. However, for certain exceptional values of the parameters these qualitative features may suddenly change under a small variation of the parameter, and these changes must be understood.

Two of the simplest singularities, the crosscap and swallowtail. The former arises, for example, in projections of surfaces in higher dimensions to 3-space, in families of projections of a space curve to a plane, and in boundaries of solution sets to certain differential equations; the latter in duals of smooth surfaces, families of plane wavefronts and caustics in 3-space. Their occurence in a wide range of applications is typical.



In spite of its fundamental character, and the central position it now occupies in mathematics, singularity theory is a surprisingly young subject. Substantial results and exciting new developments within the subject have continued to flow since it first crystallised in its current form in the mid 1960s, while the theory has embodied more and more applications.

This programme will bring together experts within the field and those from adjacent areas where singularity theory has existing or potential application. Applications of particular interest include those to wave propagation, dynamical systems, quantum field theory, and differential and algebraic geometry, but these should not be deemed prescriptive. It is the programme's aim both to foster exciting new developments within singularity theory, and also to build bridges to other subjects where its tools and philosophy will prove useful.

Geometry and Topology of Fluid Flows
September to December 2000
Organisers: H Aref (Urbana-Champaign), T Kambe (Tokyo), RB Pelz (Rutgers), RL Ricca (UCL)
The goal of this programme is to bring the disciplines of fluid mechanics and magnetohydrodynamics (MHD) together with powerful mathematical techniques in geometry and topology. Topics will include: Integrals of motion and conservation laws and their relation to the geometrical and topological structure of space; Finite-time singularities in hydrodynamics and MHD; Geometric and group-theoretic approaches to hydrodynamics with applications to stability, mixing and the global structure of complex flows; Topological description of 3D velocity and vorticity fields; Fluid kinematics and chaotic advection.

The geometrical and topological view of fluid mechanics and MHD focuses on global properties and is based on a Lagrangian representation of the flow, in contrast to the local, coordinate-based, Eulerian representation currently used in most analytical and numerical treatments of fluid mechanical problems. Because of the potential mutual benefits of connecting the field of fluid dynamics more closely to geometry, topology, dynamical systems, analysis and PDEs, pedagogical workshops and working groups are planned as well as advanced conferences. Historically, fluid mechanics has both utilised and inspired progress in mathematics. The programme will continue this tradition.

Integrable Systems
July to December, 2001
Organisers: JC Eilbeck (Heriot-Watt), AV Mikhailov (Leeds), PM Santini (Rome), VE Zakharov (Moscow)

From Individual to Collective Behaviour in Biological Systems
September to December, 2001
Organisers: H Othmer (Utah), TJ Pedley (Cambridge), BD Sleeman (Leeds)

Disordered Systems and Quantum Chaos (July to December 1997)

Report from the Organisers:

JP Keating (Bristol); DE Khmelnitskii (Cambridge); IV Lerner (Birmingham); P Sarnak (Princeton)

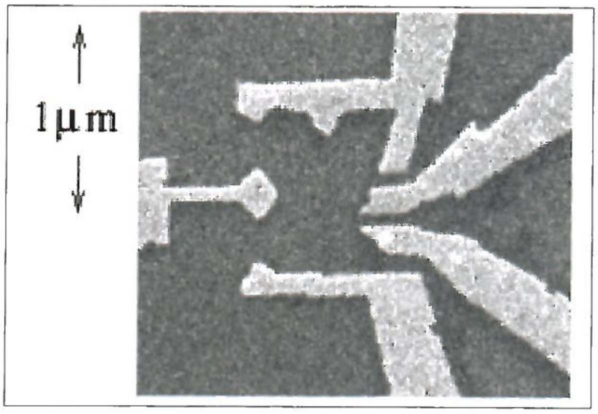
Scientific Background and Objectives

The motion of a particle in a random potential in two or more dimensions is chaotic, and the trajectories in deterministically chaotic systems are effectively random. It is therefore no surprise that there are links between the quantum properties of disordered systems and those of simple chaotic systems. The question is, how deep do the connections go? And to what extent do the mathematical techniques designed to understand one problem lead to new insights into the other?

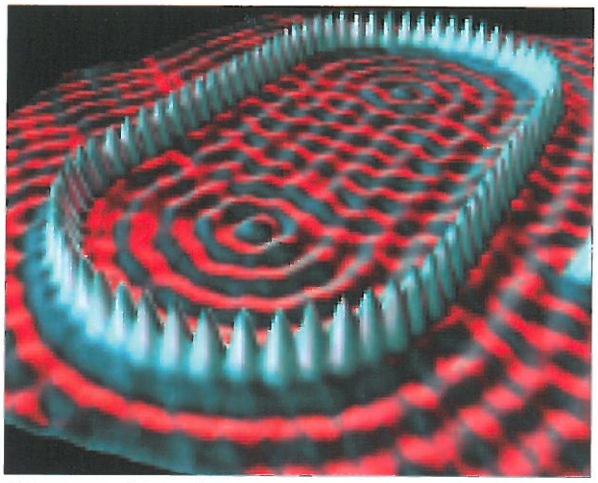
The quantum properties of disordered systems have been the focus of considerable attention in many branches of physics, most notably nuclear physics and condensed matter physics. In the last few years, advances in the field of microelectronics have shifted the focus in condensed matter physics to the study of mesoscopic systems, such as electronic devices that are large on the atomic scale but sufficiently small for quantum coherence effects to be important. In some circumstances the behaviour of these devices is governed by the fact that they have randomly distributed impurities; that is, they are disordered.

The canonical problem in the theory of disordered mesoscopic systems is that of a particle moving in a random array of scatterers. The aim is to calculate the statistical properties of, for example, the quantum energy levels, wavefunctions, and conductance fluctuations by averaging over different arrays; that is, by averaging over an ensemble of different realisations of the random potential. In some regimes, corresponding to energy scales that are large compared to the mean level spacing, this can be done using diagrammatic perturbation theory. In others, where the discreteness of the quantum spectrum becomes important, such an approach fails. A more powerful method, developed by Efetov, involves representing correlation functions in terms of a supersymmetric nonlinear σ model. This applies over a wider range of energy scales, covering both the perturbative and non-perturbative regimes.

In quantum chaos, the goal is to understand the semiclassical asymptotics of the quantum properties of individual classically chaotic systems, examples of which include simple atoms (eg helium), molecules, and also mesoscopic quantum devices.



Electron micrograph of a typical ballistic quantum dot taken from Marcus *et al, Chaos, Soliton & Fractals*, 8, 1261 (1997). Electrons are confined vertically to the ground state of a quantum well located at a GaAs/AlGaAs interface, and form a two-dimensional electron gas. A mean free path and coherence length of the order of 10 microns ensures that the carriers are coherent and ballistic.



STM image of the surface electron density of a quantum stadium corral made from Iron atoms deposited on Copper (111), taken from Crommie et al, *Nature* 363, 524 (1993)

In this case the main tool is Gutzwiller's trace formula, which, in its most general form, links the quantum energy levels and eigenfunctions in a given system to the periodic orbits of the underlying classical dynamics. Considerable attention has been devoted to understanding the conditions of applicability of this formula, in particular with regard to its accuracy and convergence properties. It is now understood how the trace formula can be used to calculate approximations to the energy levels, wavefunctions and matrix elements of a particular system from its periodic orbits, and hence how to relate quantum fluctuation statistics to statistical properties (eg ergodicity, rate of mixing etc) of the corresponding classical motion.

Despite the differences between the two approaches - one is based on ensemble averaging, the other on properties of the classical dynamics - during the last few years work on both the electronic structure of disordered systems and on quantum chaos has, to a considerable degree, been focused on the same fundamental problems, namely localisation, fluctuation statistics, and correlations in energy spectra, with a particular emphasis on their role in mesoscopic physics. The general aims of the programme were therefore to bring together researchers in the two fields, to encourage the exchange of ideas on these problems, and to concentrate on understanding the connections between field-theoretic techniques and those based on the trace formula.

The concept of localisation in disordered systems was introduced by Anderson in 1958. Localised quantum states do not contribute to the mobility in an infinite system. This leads to the metal-insulator transition when the disorder is so strong that all states in a sufficiently large system are localised. Mott showed in 1960 that, for a given disorder, all states may either be localised or extended as a function of energy, the boundary separating these two regimes being called the mobility edge. The metal-insulator transition takes place when the electrons' Fermi energy crosses the mobility edge. The modern theory of this transition in three-dimensional disordered systems is based on a one-parameter scaling conjecture (in one- and two-dimensional infinite systems all states are localised at any energy).

New phenomena, known by the general name of 'weak localisation', arise in finite low-dimensional systems that are smaller than the localisation length. While many of the most important weak localisation effects are well understood, the development of a theory for the transport and thermodynamic properties of disordered systems in the strong localisation regime, in particular at the mobility edge, remains one of the central problems of condensed matter physics. Their complete description in terms of a one-parameter scaling theory is now thought unlikely, because the wavefunctions at the mobility edge are multifractal; that is, they are characterised by a set of lengths which scale with different, independent exponents.

The quantum eigenfunctions of classically chaotic systems can also exhibit localisation. In fact, in certain cases such systems can be mapped onto the Anderson model. Considerable effort has been put into relating this behaviour to properties of the classical trajectories in the asymptotic limit as $\hbar \to 0$. Another kind of localisation observed in these eigenfunctions is 'scarring', namely the concentration of intensity around individual periodic orbits. This too is far from being well understood.

One of the specific aims of the programme was to focus on localisation phenomena and scarring in both randomly disordered and deterministically chaotic systems.

Localisation has also stimulated a great deal of interest amongst mathematicians. That eigenfunctions localise in more than one dimension is still unproved and is recognised as an outstanding problem. Likewise, there are no rigorous results concerning scarring. Over the last few years these questions have led to the development of a theory for the spectral properties of random operators, and to the study of the statistical properties of the eigenfunctions of the Laplacian on surfaces of constant negative curvature (on which the geodesic motion is strongly chaotic). Another of the specific aims of the programme was to attract researchers from the mathematical community to interact with physicists on these problems.

The importance of ensemble fluctuations in disordered systems was realised about a decade ago. Until that time, the conventional wisdom was that all disordered samples are self-averaging, so that ensemble fluctuations are no more important than, for example, thermal fluctuations in the classical Boltzmann gas. It turns out, however, that quantum coherence effects result in ensemble fluctuations which, for low-dimensional systems at zero temperature, do not vanish, even in the limit of infinite system size. At finite temperatures, quantum coherence sets a new mesoscopic scale. Since the mid-eighties, properties of electronic devices on this scale have been studied in thousands of experiments. The fluctuations measured in conductance and magnetic properties are related to correlations between the energy levels. In a certain regime, corresponding to the limit in which the dimensionless conductance tends to infinity, these correlations are universal and are directly related to those that exist between the eigenvalues of random matrices. This provides a highly successful phenomenological model which enables fluctuation properties to be calculated.

The link between the spectral correlations of randomly disordered systems in the ergodic regime (when the dimensionless conductance tends to infinity) and the eigenvalue correlations of random matrix theory was established by ensemble averaging using the supersymmetric nonlinear σ model. Building upon this, there has been considerable recent progress in developing non-perturbative techniques that encompass finite conductance corrections. One of the specific aims of the programme was to focus on these new developments.

Energy level correlations also play a central role in the theory of quantum chaos. One of the main conjectures in the subject is that generically, in the semiclassical limit, the spectral statistics of a given classically integrable system are Poissonian, whilst those of a given classically chaotic system are the same as for random matrices. This is supported by extensive numerical computations, and by theoretical arguments based on the trace formula. Recently there has been considerable progress in this direction, including calculations of the asymptotic form of the approach to the limit.

In the last two years there has been an attempt to unify these methods by constructing a nonlinear σ model for individual systems rather than for ensembles. In this case the average would be over a dynamical parameter (such as the energy) instead of different realisations of a random potential. The hope was that this would prove the energy level correlation conjectures. One of the main aims of the programme was to focus on understanding the connections between this approach and the one based on the trace formula.

A complication in this story is that some classically integrable systems are known not to have Poissonian level statistics, and the spectra of some classically chaotic systems are known not to be random-matrix-correlated. The key questions then are: what makes these examples exceptional (or non-generic); and how can this fact be accommodated into theories based either on the trace formula, or on a σ model?

There are also far-reaching connections between these problems and recent developments in number theory. First, one can construct classically integrable systems whose quantum energy levels are given by simple formulae involving sets of integers. The goal then is to prove that these are uncorrelated (ie Poisson distributed) in the semiclassical limit. Recent results have shown that this is a hard problem. In particular, it has been proved that for certain large classes of systems the levels are correlated, whilst for others they are not. Hence the question of what is meant by genericity is a key issue.

Second, some of the most widely investigated classically chaotic systems correspond to geodesic motion on compact surfaces of constant negative curvature. The corresponding quantum energy levels are the eigenvalues of the Laplace-Beltrami operator and are related to the closed geodesics by the Selberg trace formula. These have been found numerically to exhibit the same correlations as those in random matrix theory for the surfaces generated by non-arithmetic groups. For arithmetic groups, it has been proved that the correlations are almost absent; that is, the eigenvalues are almost Poisson distributed. Thus these systems provide a rich class of examples showing both generic and non-generic behaviour.

Finally, extensive numerical evidence supports the conjecture that the zeros of the Riemann zeta function and other L-functions are also correlated like the eigenvalues of random matrices, and this in turn hints at a spectral interpretation for them. In this case the explicit formula that links the zeros to the primes plays the role of a trace formula.

Another key aim of the programme was to encourage further interactions between mathematicians working on these problems and physicists interested in the analogous properties of disordered systems and quantum chaos.

Organisation

The overall organisation was undertaken by Jon Keating, David Khmelnitskii and Igor Lerner in consultation with Peter Sarnak. The pre-programme arrangements were overseen by Jon Keating, and the day-to-day administration of the programme was carried out by Jon Keating from July to September and Igor Lerner from October to December.

Many of the participants also played a substantial role in the organisation of workshops, principally Hans Weidenmüller for the NATO ASI, Jens Marklof for the Spitalfields Day, and Uzy Smilansky for the final conference.

Throughout the programme, we ran a regular seminar series on Tuesdays. There were usually three such talks each week.

Findlay Kember

Igor Lerner, Jon Keating and David Khmelnitskii

The organisation was greatly assisted by the dedicated, helpful and cooperative work of all of the staff at the Newton Institute. Without this the scientific programme could not have succeeded.

Participation

The programme attracted 66 long-term participants (whose average stay was for about 7 weeks) and 69 short-term participants (on average, staying for 11 days). In addition, about 200 researchers visited the conferences and one-day meetings. Other than when conferences were being held, the number of participants at any one time was on average about 24.

The list of participants confirms the strong interest aroused by the programme: practically all of the leading theorists in mesoscopic physics and quantum chaology and many prominent mathematicians working on related problems attended. Geographically, there were participants from most European countries (including the former Soviet Union and Eastern Europe), North and South America, the Middle and Far East. In particular, support from the Leverhulme Trust enabled us to invite many scientists whose home institutions are in the former Eastern Bloc or in Latin America.

Younger researchers were encouraged to attend by making use of the Junior Membership scheme. This was particularly successful in helping to attract post-doctoral researchers and PhD students.

UK researchers were also specifically targeted. In total 13 of our long-term participants and 32 of our short-term visitors were from UK institutions. Many others came to the conferences and workshops.

Meetings and Workshops

We had three long workshops and two one-day meetings. These were as follows.

EC Summer School on Disordered Systems and Quantum Chaos
Organisers: Jon Keating, David Khmelnitskii, Igor Lerner
This School was held at the beginning of the programme, during the period 28 July - 1 August. The idea was that it would provide an impetus to the whole programme and would help set the agenda. The topics covered included the quantum field theory of disordered systems, quantum localisation in classically chaotic systems, rigorous mathematical results concerning localisation, symbolic dynamics, random matrix theory as a model for the statistical properties of quantum spectra, the Riemann zeta function, wavefunctions in disordered systems, rigorous results on spectral statistics, disordered superconductors, and quantum graphs. Lectures were specifically coordinated so as to allow participants to compare and contrast the various different approaches.

The Lecturers were: A Altland (Cambridge), MV Berry (Bristol), EB Bogomolny (Orsay), V Falko (Lancaster), S Fishman (Haifa), I Goldsheid (London), DE Khmelnitskii (Cambridge), IV Lerner (Birmingham), YG Sinai (Princeton), U Smilansky (Weizmann Institute), BZ Spivak (Seattle), M Wilkinson (Strathclyde), S Zelditch (Baltimore), and MR Zirnbauer (Cologne).

The School attracted in total 57 advanced graduate students, postdoctoral fellows and young researchers, mainly from EC countries. All were invited to present posters at an afternoon-long session. Many did.

Findlay Kember

Coffee break during a workshop

NATO ASI Supersymmetry and Trace Formulae: Chaos and Disorder
Director: Igor Lerner. Organising Committee: Jon Keating, David Khmelnitskii, Peter Sarnak and Hans Weidenmüller
This Advanced Study Institute was one of the main focal points of the programme. The aim of the lectures was both to present a coherent and comprehensive overview of the modern quantum theory of disordered and chaotic systems, and to discuss recent results in the field. The courses were complemented by selected research seminars, and by posters presented at an afternoon-long session.

The subjects covered in the courses included a quantum interpretation of some properties of the Riemann zeta function, the semiclassical theory of spectral statistics, the pair correlation of the Riemann zeros, classical trace formulae, quantum field theory and the nonlinear σ model, non-exponential relaxation in disordered systems, semiclassical trace formulae, scarring in quantum wavefunctions, a field-theoretic approach for chaotic systems, parametric statistics, rigorous results for level correlations and the Riemann zeros, the scattering matrix approach and random matrix theory.

The lectures were given by: MV Berry (Bristol), EB Bogomolny (Orsay), P Cvitanovic (NBI), KB Efetov (Bochum), MC Gutzwiller (IBM), F Haake (Essen), E Heller (Harvard), JP Keating (Bristol), DE Khmelnitskii (Cambridge), VE Kravtsov (Trieste), S Fishman (Haifa), P Sarnak (Princeton), BD Simons (Cambridge), U Smilansky (Weizmann Institute), M Wilkinson (Strathclyde), HA Weidenmüller (Heidelberg), and MR Zirnbauer (Cologne). Most will be published in a NATO ASI volume by Plenum.

The workshop was extremely successful and we received many favourable comments from the participants.

One-Day Conference on Physics in Mesoscopic Conductors
Organiser: David Khmelnitskii
This one-day meeting was sponsored by the Mathematical Physics Group of the Institute of Physics. The idea was to highlight new directions in experimental mesoscopic physics for the participants of the programme, mainly theoretical physicists and mathematicians. The Conference attracted about 50 participants from different UK institutions.

The talks were given by L Eaves (Nottingham), R Nicholas (Oxford), M Pepper (Cambridge), and V Petrashov (Royal Holloway).

Spitalfields Day: Zeta Functions and Spectra
Organisers: Jon Keating and Jens Marklof
This meeting was supported by the London Mathematical Society. The aim was to focus on the links between the theory of spectra and the properties of the Riemann zeta function, and to stimulate discussion of recent developments in the spectral interpretation of the Riemann zeros.

The lecturers were: A Connes (IHES), DR Heath-Brown (Oxford), D Hejhal (Minnesota), M Huxley (Cardiff), and Z Rudnick (Tel Aviv).

The meeting attracted over 100 participants.

Final Conference: Quantum Chaos and Mesoscopic Systems
Organisers: Jon Keating, David Khmelnitskii, Igor Lerner and Uzy Smilansky
The final conference was an opportunity for participants to present work completed during their stay at the Institute. It also provided a forum to summarise the conclusions reached during the programme.

Lectures were given by: N Argaman (UCSB), H Baranger (Bell Labs), C Beenakker (Leiden), EB Bogomolny (Orsay), G Casati (Como), I Dana (Bar-Ilan), V Falko (Lancaster), M Fromhold (Nottingham), Y Gefen (Weizmann Institute), F Izrailev (Universidad de Puebla, Mexico), L Kaplan (Harvard), S Kravchenko (City College, NY), A MacKinnon (Imperial College), C Marcus (Stanford), J Marklof (Bristol), G Montambaux (Orsay), T Monteiro (University College London), T Nieuwenhuizen (Amsterdam), F von Oppen (Heidelberg), J-L Pichard (Saclay), R Prange (Maryland), JM Robbins (Bristol), AD Stone (Yale), and A Voros (Saclay).

Topics included recent experiments on mesoscopic devices, intermediate statistics, scarring of quantum wavefunctions, spectral statistics in integrable systems, localisation, and the Pauli exclusion principle.

Findlay Kember

Participants at the final conference (left to right): Richard Prange, André Voros, Alfredo Ozorio de Almeida

Outcome and Achievements

The main achievement of the meeting was that it brought together researchers from an uncommonly wide range of backgrounds, stretching from experimental condensed matter physics to number theory, to focus on fundamental issues in the theories of disordered systems and quantum chaos, and on their links with various problems in mathematics. This worked surprisingly well: almost all participants made serious attempts to interact with those from the other areas, and most who did reported positive results.

It was expected that those with interests in disordered systems and quantum chaos would find much in common, and this proved to be the case. More remarkable was the degree of common interest both groups found with the mathematicians who participated.

The programme focused on the following problems: the statistics of quenched (mesoscopic) fluctuations and spectral correlations, and, in particular, generic features in their deviations from universality; the existence of a wider set of universality classes within the nonlinear σ model related to the Cartan classification of symmetric spaces; the limits of validity of the Bohigas-Giannoni-Schmit conjecture, which concerns the link between spectral statistics and random matrix theory in classically chaotic systems; the Berry-Tabor conjecture, which states that the corresponding statistics in classically integrable systems are Poissonian, and Berry's conjecture that the quantum eigenfunctions of chaotic systems exhibit Gaussian random fluctuations in the semiclassical limit; the scarring of eigenfunctions and the existence of nontrivial wavefunction statistics in quantum disordered systems; multifractality in eigenvalue and eigenfunction distributions; thermodynamic and transport properties of nanoscale quantum dots; non-exponential relaxation processes in ballistic and disordered quantum dots; eigenvalue correlations in systems described by non-hermitian Hamiltonians; and interaction effects in the description of spectral correlations in quantum dots.

The main outcome of the programme was the emergence of a more coherent view of the links between these problems. It is difficult to predict at this stage what long-term consequences this will have, but some of the main short-term achievements and conclusions are outlined below.

As anticipated, the main focus of the programme was on spectral statistics. First, the application of a field-theoretic approach within the framework of the nonlinear σ model to the description of the energy level statistics of individual chaotic systems is a very exciting prospect, but has turned out to present a number of fundamental mathematical and physical problems. Some of these were overcome during the programme (mainly in work by A Altland, BD Simons and MR Zirnbauer), but many remain to be solved. The results of Zirnbauer's extension of these ideas to quantum maps suggests that the way forward might be to consider averages over a very small amount of disorder. However, at this stage the question of whether one can avoid an ensemble average altogether is, for typical systems, still open. This is likely to remain one of the key directions of research in the future.

There were also significant steps in the extension of semiclassical methods to the description of level statistics in disordered systems (IV Lerner and RA Smith in collaboration with BL Altshuler). These appear to be particularly useful in describing behaviour in the non-ergodic regime, where the spectral correlations do not exhibit random-matrix universality. In the ergodic regime the use of diagrammatic techniques allows one to identify the trajectories responsible for the deviations from the diagonal approximation at short times.

D Cohen, U Smilansky and G Tanner worked on the related problem of periodic orbit correlations in chaotic systems. Many participants contributed to discussions on this subject, which remains one of the most mysterious in the field. It is hoped that the numerical investigations started at the Institute, coupled with insights obtained by comparison with the diagrammatic method, will shed some new light on the problems involved.

Findlay Kember

Uzy Smilansky

U Smilansky investigated eigenvalue correlations for quantum graphs. This led to considerable interest in these models amongst both the mathematicians and those working on disordered systems, in particular because in this case the trace formula is exact rather than a semiclassical approximation.

S Fishman and F Haake both developed techniques to calculate the eigenvalues of the Perron-Frobenius operator as part of a project involving many of the participants to investigate the role these play in the description of deviations from random matrix theory in spectral statistics. Discussions with I Goldsheid were particularly helpful in characterising the mathematical basis of their results. These questions are also central to the approach based on the ballistic nonlinear σ model (O Agam, BD Simons).

JP Keating worked with MV Berry and SD Prado to develop a semiclassical theory for the influence of orbit bifurcations on spectral statistics in mixed systems, and together with S Fishman used a construction involving the Aharonov-Bohm effect to calculate the range of validity of the diagonal approximation in theories of spectral statistics based on the trace formula.

There was also a great deal of activity on the autocorrelations of eigenstates in disordered and chaotic systems, and in particular on their relation to eigenvalue correlations in the non-ergodic regime. This is of central importance to the Anderson localisation problem, because it has become clear that the new universal regimes for level correlations which emerge at the mobility edge (VE Kravtsov, IV Lerner; AD Mirlin) are crucially affected by the multifractal character of the eigenstates (JT Chalker, VE Kravtsov, IV Lerner, RA Smith).

The autocorrelation properties of eigenfunctions were also investigated in the ergodic and weak-localisation regimes (AD Mirlin; YV Fyodorov; M Srednicky; IV Yurkevich, VE Kravtsov). In the weak localisation regime B Muzykantskii and DE Khmelnitskii have developed a new instanton approach, based on the existence of a non-trivial inhomogeneous saddle-point in the σ model, that has led to results concerning multifractality and long-time relaxation processes due to untypical realisations of the disorder (B Muzykantskii and DE Khmelnitskii; V Falko and KB Efetov; KM Frahm; AD Mirlin). It turns out that this has a very natural counterpart in a time-dependent field-theoretic approach to the study of different models of turbulence at intermediate scales. Further research in this direction seems to be very promising.

On the question of localisation in quantum chaotic systems, G Casati and R Prange both worked on compact billiards that exhibit diffusion in angular momentum (specifically, a Bunimovch stadium that is almost circular). Such systems have quantum wavefunctions that are localised in the angular momentum basis. JP Keating and G Tanner constructed a semiclassical periodic orbit description of the spectral statistics of these systems.

EJ Heller and L Kaplan developed a very promising nonlinear theory of scars. This stimulated a lively debate on the links with an alternative approach based on the trace formula. The possibility of a unified description is under current investigation.

Several participants worked on applications of the methods described above. For example, M Wilkinson collaborated with B Mehlig and K Richter on applying semiclassical methods to calculate polarisation effects in small metallic particles. HA Weidenmüller worked on extending the statistical description based on the σ model to classical wave scattering.

The statistical distribution of the eigenvalues in non-hermitian systems proved to be another direction of research in which very different approaches appear to be converging. While non-hermitian systems have been studied in the context of turbulence for some time, their importance in condensed matter physics has been recognised only recently, mainly in relation to certain problems in the quantum Hall effect. KB Efetov calculated the distribution of the eigenvalues in the complex plane for a model associated with an imaginary vector potential using the supersymmetric σ model, and JT Chalker applied diagrammatic perturbation theory to calculate the corresponding distribution for advective diffusion. Remarkably, many of the same models have also recently been considered in a purely mathematical context (I Goldsheid and B Khoruzhenko) and this stimulated considerable activity during the programme.

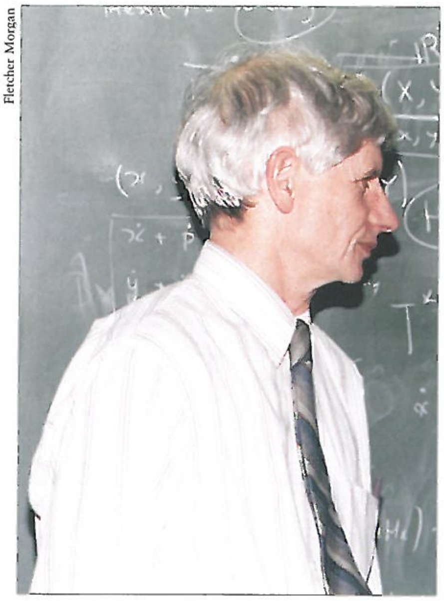
One of the most remarkable features in the theory of disordered systems is that many experimental data can be well understood within the model of non-interacting electrons. However, new experimental results on the energy level correlations in nanoscale quantum dots (reported by C Marcus), and on the existence of a metal-insulator transition in two-dimensional silicon structures in contradiction to the standard scaling theory (S Kravchenko and collaborators), have highlighted the necessity to include interactions. Thus the treatment of 'strong correlations', which is central to many areas of condensed matter theory, is now beginning to become important on the mesoscopic scale. Considerable progress has been made in understanding the effects of interactions on level statistics and transport properties in quantum dots (Y Gefen and A Kamenev; B Spivak; Y Imry; S Levit), but the characterisation of their influence on the metal-insulator transition remains an outstanding challenge.

As has already been mentioned, some of the most exciting developments centred around the interactions between physicists and mathematicians. In particular, A Connes presented his results concerning a spectral interpretation of the Riemann zeros, and a possible approach to proving the Riemann Hypothesis. Z Rudnick played a key role in explaining these ideas, and this in turn stimulated work by MV Berry and JP Keating in the same direction.

S Zelditch initiated work with M Zirnbauer to construct a rigorous mathematical framework for the σ model, and with J Marklof and Z Rudnick to compute the level statistics for a class of integrable systems using estimates for trigonometric series. J Marklof discovered a deep relationship between the pair correlation of the energy levels of rectangular billiards and the mixing properties of a dynamical system defined on a product space of hyperbolic surfaces. This allowed him to prove several strong results about the Poisson conjecture for the level statistics. Finally, MV Berry and JM Robbins investigated the consequences for isospin of their work on the Pauli exclusion principle after discussions with DJ Thouless.

It will be clear from the above that the range of collaborations started during the programme was extremely broad. As many of the participants commented, this was due to a large extent to the uniquely stimulating environment provided by the Newton Institute and maintained by its staff.

Fletcher Morgan



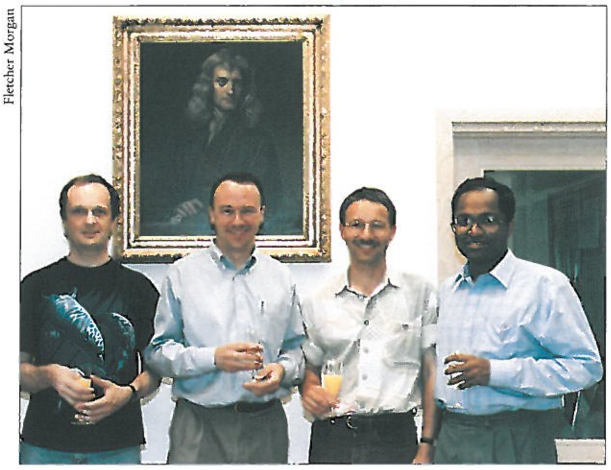
David Thouless, after presenting an Institute Seminar

Neural Networks and Machine Learning (July to December 1997)

Report from the Organisers:

CM Bishop (Microsoft/Edinburgh), D Haussler (UCSC), GE Hinton (Toronto), M Niranjan (Cambridge), LG Valiant (Harvard)

Fletcher Morgan



Stephen Luttrell, Christopher Bishop, Joachim Buhmann and Mahesan Niranjan at an Institute reception

Introduction

The first mathematical models of artificial neural networks were proposed in 1943 by McCulloch and Pitts, who demonstrated that networks of simple threshold units were capable of universal computation. By the 1960s, neural networks had become the focus of extensive research, much of which was concerned with the abilities of adaptive networks to learn from data sets. This did not, however, lead to large-scale applications, largely as a consequence of fundamental limitations of the algorithms considered at that time.

Following many years of relative inactivity, the field experienced rapid growth during the 1980s and 1990s, stimulated by the development of new algorithms which overcame the limitations of earlier approaches, and by the widespread availability of fast computers. During this period the close links between neural network models and the concepts of conventional statistical pattern recognition were clarified, leading to a stronger theoretical foundation for neural network algorithms, as well as to more effective practical exploitation. Theoretical insight into neural network models has also come from computational learning theory, approximation theory, dynamical systems theory and information geometry. These disparate viewpoints often provide complementary insights.

The mathematical foundations of neural networks are currently being studied by several different communities of researchers including computer scientists, statisticians and physicists. One of the aims of the programme *Neural Networks and Machine Learning* at the Isaac Newton Institute was to promote greater interdisciplinary collaboration between these different groups. One aspect in particular, namely the interaction between researchers in mainstream neural computing and in the field of probabilistic graphical models, was especially successful.

Organisation

The overall planning of the programme was undertaken by Christopher Bishop, with the other organisers (as well as some participants) being involved in the arrangement of specific workshops, conferences and seminar series.

The programme was the largest international event of its kind to have been held in the field. Many of the world's leading researchers in neural computing participated in the programme, for periods ranging from one or two weeks up to six months, and numerous younger scientists benefited from workshops and tutorials. An overview of the workshops is given below.

Regular seminars, organised by Mahesan Niranjan, were run during the weeks between workshops. Several of these comprised tutorials on specific subjects aimed at non-specialists and these proved to be particularly useful in allowing participants to learn about new topics. It was found that about two or three such seminars per week was an appropriate number in maintaining a sense of ongoing activity in the programme while allowing participants adequate time to pursue their own research or to engage in collaborative work. There was an excellent atmosphere of lively interaction during the programme, and we are aware of a significant number of new collaborations which have emerged.

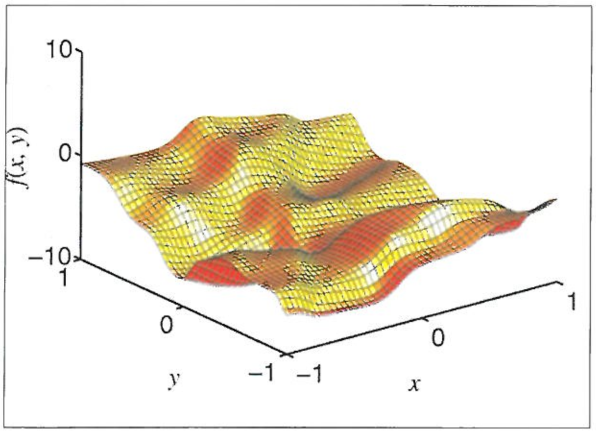
Two of the seminars in the Newton Institute Seminar Series were presented by workshop participants: *Neural Networks: A Probabilistic Perspective* (Christopher Bishop) and *Statistical Genome Analysis using Hidden Markov Models* (David Haussler).

Social events were organised throughout the programme, and these proved to be invaluable in helping participants to get acquainted. The personal reports produced by participants were generally highly positive. In particular, many of the participants commented on the unique and highly stimulating research environment offered by the Newton Institute, and on the tremendous support provided by the Institute staff.

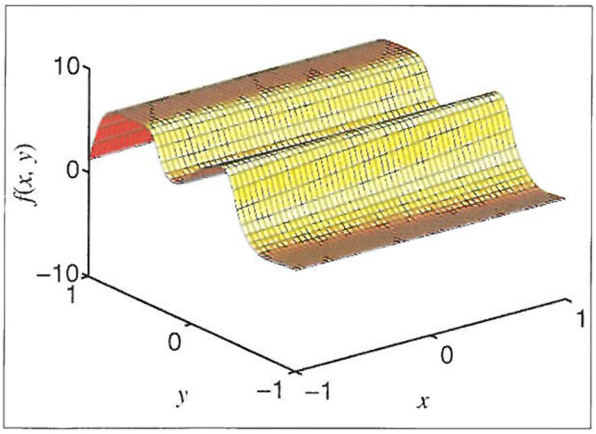
Workshops

NATO Advanced Study Institute

The first workshop of the programme was a two-week NATO Advanced Study Institute on *Generalisation in Neural Networks and Machine Learning* which took place from 4 to 15 August (Director: Christopher Bishop; co-organisers: Joachim Buhmann, Geoffrey Hinton and Michael Jordan). This was heavily over-subscribed and attendance was limited to around 110 by the capacity of lecture room 1. Several complementary perspectives on generalisation were covered in this workshop, including both Bayesian and frequentist viewpoints. By reviewing many of the key theoretical concepts underpinning the field of neural computing, the NATO ASI provided an excellent start to the overall programme, as well as giving younger scientists the chance to hear tutorial talks by leading researchers in the field. The scientific and social aspects of the programme were both very successful, and a proceedings volume will be published in the NATO series by Springer towards the end of 1998.



A sample from the prior distribution over functions $f(x,y)$, for a multi-layer neural network having two inputs x and y, induced by a Gaussian prior over the network parameters.



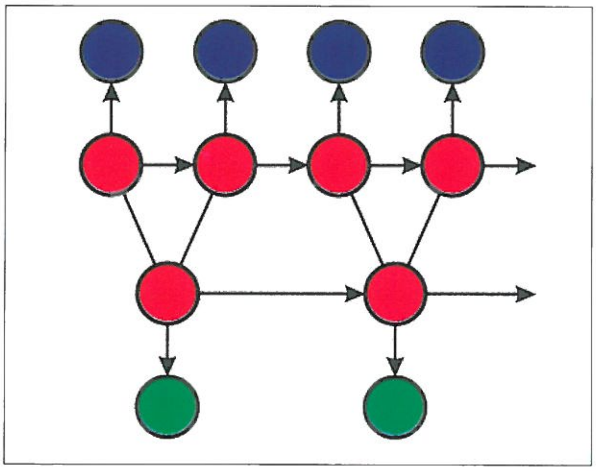
A sample from the distribution of network functions in which input x has a much lower relevance than input y.

Pulsed Neural Networks

A two-day workshop on *Pulsed Neural Networks* was held on 26 and 27 August, and attracted around 60 people (double the number expected). The majority of artificial neural network models are based on the propagation of continuous variables from one processing unit to the next. In recent years, data from neurobiological experiments has made it increasingly clear that biological neural networks, which communicate through pulses, use the timing of these pulses to transmit information and to perform computation. This realisation has stimulated a significant growth of research activity in the area of pulsed neural networks, including theoretical analysis as well as the development of new computational paradigms. As a result of this workshop, it was decided to write a multi-authored book involving twelve invited contributions from workshop speakers (edited by Wolfgang Maass and Christopher Bishop) which will be published by MIT Press in November 1998.

EC Summer School

An EC Summer School on *Probabilistic Graphical Models* was held from 1 to 5 September (organised by Christopher Bishop and Joe Whittaker). This workshop was outstandingly successful and generated considerable enthusiasm from the lecturers and participants. It was run as a mixture of 90-minute tutorials in the mornings and 30-minute advanced research talks in the afternoons and ensured that both lecturers and students could derive maximum benefit. A key feature of this workshop was the interaction between neural computing and graphical model researchers, and this is discussed further below.



A chain graph (containing both directed and undirected edges) representing two coupled hidden Markov models, as might be used to model concurrent audio and video signals. The blue nodes denote successive audio observations, while the green nodes represent video observations having a lower sampling rate. The red nodes correspond to 'hidden' variables which give the model its rich probablistic structure.

Analysis of DNA Sequences
A workshop on *Statistical Analysis of DNA and Protein Sequences* (organised by David Haussler and Richard Durbin) took place from 20 to 24 October. This was highly topical and attracted a strong participation. This workshop provided something of a precursor to the 1998 programme on *Biomolecular Function and Evolution in the Context of the Genome Project.*

Bayesian Methods
The final programme conference was on *Bayesian Methods* and was held from 15 to 19 December (organised by Christopher Bishop and Mahesan Niranjan). Again this was very well attended and formed an excellent conclusion to the six-month programme, with Geoffrey Hinton giving the keynote presentation. It also provided an opportunity for some of the programme participants to present results of research conducted while resident at the Newton Institute.

Geoffrey Hinton giving his keynote presentation

Themed weeks
In addition to the main conferences, we also ran four 'themed weeks', which tended to be less formal, and hence more interactive, than the larger conferences. The typical number of participants was around 30, and the seminars were generally held in lecture room 2.

The first themed week was on the topic of *Learning in Computer Vision*, and was arranged by Andrew Blake, David Mumford and Alan Yuille. It provided a direct link with the earlier Newton Institute programme on *Computer Vision*, and many of the participants in the themed week were also participants in that programme.

A week on *Applications of Neural Computing* was run from 3 to 7 November, organised by Lionel Tarassenko and Stephen Roberts. The focus was on the interplay between underlying theory and practical implementations. Presentations covered many of the most exciting and successful practical applications of neural networks.

Finally, the topic of *On-line Learning* was explored in depth during the week of 17 to 21 November, organised by David Saad. This themed week has resulted in a multi-authored book (edited by David Saad) based on the research presented at the Institute.

Achievements
Amongst the many successes of the programme, one of the most notable was the stimulation of new interdisciplinary collaboration between the neural computing and the probabilistic graphical model communities. This was reflected in the highly successful EC workshop, and was promoted by the long-term participation of several key graphical model researchers. The Newton Institute programme represented the first occasion on which these two communities have interacted so closely over an extended period. A great deal of positive feedback was received from participants both during the EC workshop and afterwards by email, and the workshop was described by several people as a landmark event.

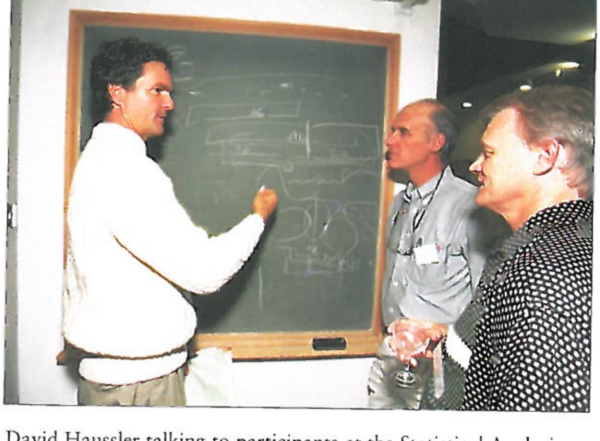
Thomas Richardson from the University of Washington was elected as Rosenbaum fellow. Amongst the research carried out during his stay at the Institute, he developed a new type of graphical model designed to represent the Markov structure that a latent variable model induces over its observed margin. He showed that Gaussian mixed ancestral graphs are in fact curved exponential family models, and hence such graphs describe a manifold in parameter space, whereas a typical latent variable model does not. As a consequence the Bayesian information criterion (BIC) is consistent for mixed ancestral graph selection, ie in the asymptotic limit BIC will assign the highest score to the true model.

Christopher Bishop (Microsoft/Edinburgh), Brendan Frey (Illinois) and Neil Lawrence (Aston) have explored novel approximating distributions for variational inference and learning in densely connected Bayesian networks. Exact inference is intractable in such models, and standard mean field theory addresses this problem by assuming complete factorisation. They showed that a much richer approximating distribution, involving a Markov chain framework, also leads to a tractable algorithm.

Joe Whittaker (Lancaster) and Alberto Roverato (Lancaster) developed a new importance sampling approach for the evaluation of normalising constants in non-decomposable Gaussian graphical models. The sampler is based on the asymptotic distributions of either the maximum likelihood estimates or of the posterior distribution in a conjugate analysis. Two problems had to be addressed. First, the support of the required distribution is that of a positive definite matrix constrained by a particular structure of zeros. (Sampling from standard matrix distributions such as the Wishart would give zero support to the required distribution.) Second, careful numerical implementation is required to ensure that the shape of the required distribution is accurately tracked by the sampler in spaces of high dimensionality.

Milan Studeny (Prague) developed and presented a new, direct separation criterion for chain graphs, and showed that it is equivalent to a classical moralisation criterion. A chain graph is a probabilistic graphical model admitting both directed and undirected edges, with (partially) directed cycles forbidden. Using the new criterion he then proved that for every chain graph there exists a strictly positive definite probability distribution that embodies exactly the independency statements displayed by the graph, thereby justifying the use of chain graphs as a tool for the description of conditional independence structures.

Tommi Jaakkola (UCSC) and David Haussler (UCSC), motivated by problems in biosequence analysis, have developed novel kernel-based methods which combine discriminative and generative approaches. Biosequence analysis relies to a large degree on the assessment of similarity between DNA or protein sequences. It is therefore important that the statistical techniques employed for the analysis make this similarity measure explicit. Several (discriminative) methods, such as support vector machines and Gaussian process classifiers, provide means for explicitly characterising the similarity metric. While certainly powerful, these methods nevertheless lack the ability to deal well with the inherent variability of biosequences for which generative statistical models in turn are more appropriate. Ideally, these complementary approaches should be combined. This research has indeed led to the development of a general framework for combining generative models with discriminative (kernel) methods, motivated by considerations from information geometry, thus establishing a new class of statistical tools.



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David Haussler talking to participants at the Statistical Analysis of DNA workshop

Mahesan Niranjan continued his work on Bayesian methods applied to signal processing problems, particularly the problem of speech enhancement. Using Bayesian methods he showed how to estimate the noise statistics from corrupted data without the need to segment the speech from the background noise. This leads to an algorithm with which it is possible to enhance speech corrupted by white noise, and the approach permits a natural extension to deal with coloured noise.

David Haussler (UCSC) and Manfred Opper (Aston) considered the problem of sequential prediction under log loss, in a scenario in which a player tries to minimise his loss relative to the loss of the (with hindsight) best distribution from a target class for the worst sequence of data. They obtained bounds on the minimax regret in terms of the metric entropies of the target class with respect to suitable distances between distributions. In addition, they showed that such a worst case scenario leads to prediction strategies which also work well in a less pessimistic, average case situation provided the model class is not too complex.

Shun-ichi Amari (Tokyo) visited the Institute for three weeks and presented some of his recent work on the information geometry view of learning in neural networks and other probabilistic models, including a unified perspective on the various techniques for independent component analysis. One of the developments to have emerged from this work is the use of the natural Riemannian gradient for on-line learning. It is anticipated that this algorithm is not only asymptotically efficient but may eliminate the so-called plateaux associated with conventional gradient descent learning which give rise to extremely slow convergence. During Amari's visit, Magnus Rattrey (Aston) and David Saad (Aston), in collaboration with Amari, developed an analysis of the performance of natural

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Shun-Ichi Amari and Richard Rohwer

gradient descent within the statistical mechanics framework, and were able to go beyond the asymptotic regime. The Riemannian gradient has also been applied to the problem of independent component analysis in the case where the number of source signals is unknown. Usually the number of observations is larger than that of the sources but they are noise contaminated. In this case the parameter space forms a Stiffel manifold, and an explicit formula has been obtained for the natural gradient.

Acknowledgements

The programme benefited from sponsorship by British Airways, Rolls Royce and British Aerospace, as well as from an arrangement with Silicon Graphics which significantly enhanced the UNIX computer facilities available to participants. We are grateful to all of the sponsors for their generosity. We would also like to express our sincere thanks to the staff of the Isaac Newton Institute, for their energy, enthusiasm and general support throughout the six-month programme.

Dynamics of Astrophysical Discs (January to June 1997)

Report from the Organisers:

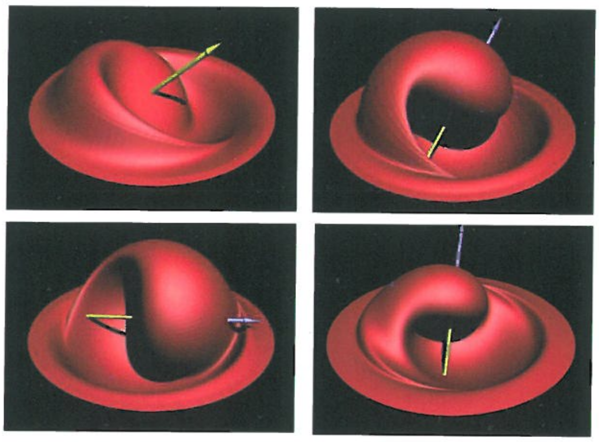
J Goodman (Princeton), JCB Papaloizou (QMW), JE Pringle (Cambridge), JA Sellwood (Rutgers)

Scientific Background and Objectives

Configurations taking the form of a flattened disc commonly occur in astronomy. When highly flattened, the material in these objects typically orbits in circles such that centrifugal force to a first approximation balances a gravitational attracting force. The latter is often due to some external gravitational potential into which the matter has fallen, but can also, in part or in whole, be caused by the self-gravity of the material itself.

Discs form whenever the material within them can 'cool' on a shorter timescale than the one on which it can transport away its angular momentum. The material itself can come in a variety of forms.

In disc galaxies, the material is in the form of stars, which obey the equations of collisionless stellar dynamics. In Saturn's rings (and in other planetary ring systems), the material consists of particles with sizes which range from those of rocks and boulders down to those of marbles and dust. Planetary rings are marginally collisional in that typical mean free paths are comparable to the vertical thickness. Discs consisting of dust, and also probably larger sized particles whose infra-red emission cannot be detected, are being discovered around a number of young main sequence stars. These discs are thought to be the remnants of the process of planet formation.



Various stages in the evolution of a twisted disc. At each radius in the disc, material is rotating in a ring about the central body (for example a black hole in the centre of an active galactic nucleus). The disc is assumed to be illuminated by an isotropic light source at the centre, and because the disc is warped, the disc is illuminated non-uniformly. The backreaction which occurs when the local disc elements reradiate the incoming light causes torques on the various disc elements. These torques cause the disc elements to continue to twist and precess gyroscopically in a chaotic manner. The disc has been scaled logarithmically so that the inner edge is r=1 (log r = 0), and the outer edge is $r = 10^4$ (log r = 4)

Full details are to be found in Pringle (1997) MNRAS 292, 136

Gaseous discs are observed around compact objects in interacting binary star systems, and around very young stars which are still in the process of forming. They are widely believed to occur around massive black holes in the active nuclei of galaxies. These discs consist of highly ionised plasma, so that in them magnetic as well as purely hydrodynamic processes have to be taken into account.

Scientific Programme

Although astrophysical discs come in a variety of forms and have a wide range of length scales ranging from planetary to galactic, there can be a lot of common ground between them because of similar underlying dynamical properties. For this reason research problems in the area were grouped together according to similarity of dynamical properties, rather than under astronomical field.

One of the main benefits accruing from this research programme was that researchers working in different areas of astronomy, but on essentially similar problems were brought together and were able to compare methodology and discuss the results of ongoing work.

The programme involved people working in the general areas of hydrodynamics, magnetohydrodynamics, stability of self-gravitating differentially rotating systems, and the theory of turbulent dissipative fluid systems as they relate to astrophysical discs. Both analytic approaches and numerical simulations were involved.

The programme was split into three distinct, but related, phases in which different aspects of the dynamics of astrophysical discs were addressed.

1) Angular momentum transport

The long-term evolution of astrophysical discs is controlled by the rate at which angular momentum is transported outwards so allowing the disc material to sink deeper in the gravitational potential well. Associated with this process is dissipation of energy, and it is this 'accretion luminosity' which attracts the attention of astronomers in the x-ray emitting binary stars and in active galactic nuclei. We explicitly excluded detailed consideration of these thermal processes from the programme because emission processes are always found to be specific to particular astronomical objects, and give little opportunity, if any, for cross-field fertilisation. However, consideration was given to where the energy is dissipated as this can have feedback into the disc structure, and so affect the angular momentum transport process.

Various mechanisms which can provide/affect angular momentum transport were considered:

For discs with non-negligible self-gravity non-axisymmetric self-gravitational instabilities are able to set in and transport angular momentum. These are thought to give rise to the spiral arms seen in disc galaxies, accompanied with the complication that the small amount of gas in the galaxies acts as a tracer for the spiral instabilities present in the stellar component.

Recent work on non-axisymmetric waves in galactic disks has focused on the importance of co-rotation. Any orbiting density fluctuation induces a supporting spiral response from the surrounding disk that co-rotates with the fluctuation. A random distribution of density fluctuations therefore induces a "kaleidoscope" of transient spiral patterns with no particular symmetry preferred. More organised patterns may result from Landau excitation of waves from steep gradients in the density distribution. Such gradients could be created by resonant scattering from a previous wave, suggesting the possibility of a recurrent and self-perpetuating cycle of instabilities.

The discs around protostellar objects are almost certainly self-gravitating during the early part of their lives, although at later times, the central star dominates the gravitational potential. The discs around planets such as Saturn's rings are marginally self-gravitating. The outer regions, and therefore the most readily observed parts, of the discs around active galactic nuclei are also calculated to have non-negligible self-gravity.

With regard to purely hydrodynamic phenomena, little progress has been made. The discs have a strong shear flow, so that one might expect hydrodynamic turbulence to set in. However, discs rotating with Kepler's law are strongly stably stratified in the radial direction (Rayleigh criterion), and no linear or non-linear hydrodynamic instabilities have yet been found when boundaries are not reflecting. Although there is still no formal proof of nonlinear stability, with existing analytic treatments leaving the question open, this problem was widely discussed and some of the participants have embarked on collaborations to expand the parameter space that can be shown to be stable using numerical simulations and to attempt new analytic approaches.

There are additional possibilities for instability and angular momentum transport associated with wave propagation in a disc with at least one reflecting boundary. A disc with an inner edge has the possibility of supporting non-axisymmetric wave modes which propagate backwards azimuthally with respect to the fluid, but forwards in an inertial frame. Such modes can then grow by radiating angular momentum radially outwards. The presence of such processes in a disc depends on the disc being able to support locally trapped modes, and on the propagation properties through the disc. Some of the participants made progress on looking at this problem when the disc contains a global magnetic field allowing the propagation of Alfvén waves which provide the mode of angular momentum loss. Such considerations may be important for understanding MHD outflows but much more remains to be done.

There was interest in the possibility of setting up a self-sustaining hydromagnetic dynamo in which the required transport is provided through Maxwell stresses. This has been stimulated by the (re)discovery by astrophysicists of an MHD instability whose relevance had been overlooked by the MHD and dynamo community. Numerical computations had already begun to confirm that a self-sustaining dynamo can occur, and that it is this instability which enables the dynamo to exist, rather than the more familiar 'alpha-omega' dynamo mechanism involving background turbulence. However, the applicability of some form of mean field theory was discussed which does seem to be able to fit some aspects of some of the simulations. This would be useful for a possible global description of the disc as simulations at present can only be carried out for a local piece of disc. Discussion of how to extend the simulation boundary conditions to be applicable to a force free corona took place. This is a fast moving area, and one of considerable importance for disc dynamics. It is probably related to the observational evidence that discs around protostars and in active galactic nuclei (AGN) appear to be capable of driving collimated and powerful jets along the disc axis, almost certainly powered by some MHD process. Tying the dynamo generation of fields in the disc, to the MHD driving of these jets is a big challenge in this area. A further consideration is that such MHD-driven outflows can also carry off angular momentum and so enhance the dynamical evolution of the disc.

Work was also begun to study disc oscillations in the presence of MHD turbulence by simulation methods. Such studies of the response produced in the turbulent steady state under varying conditions, such as angular velocity profile, may be useful for disc diagnostics. An example is to study conditions when the epicyclic frequency has a maximum (expected near a black hole) to see whether any characteristic oscillation signature may be obtained. In the Keplerian case epicyclic oscillations making up a linear vertical shear were found to have a surprisingly long life.

2) The shape of the discs

The simplest discs to consider are those whose elements follow circular orbits around a central potential in the same plane. However, due to interactions with external forces, discs are often neither coplanar nor circular. The dynamics of such discs was explored.

The dynamics of warped galaxy disks, in which the restoring force is self-gravity has been explored by analytic and by numerical means. A number of ideas to account for bends observed near the edges of galaxy discs have been explored, survivability is questionable since self-gravity which might hold things together, even in galaxies, seems too weak to overcome the differential precession rates. The difficulty is compounded by the existence of two effects that damp bending waves: Landau damping by stars in the disk whose natural vertical oscillation frequency is commensurate with the forcing frequency of the wave, and dynamical friction with halo material. Ideas that have been explored for warp excitation involve external processes, such as material infall.

A certain amount of work has also been carried out on eccentric and non-planar particle discs around planets. However, the situation with regard to fluid discs is much less clear. Some work has been done for example on marginally warped (linear or weakly nonlinear theory is assumed) fluid discs, that is those in which the tilt angle is much less than the opening angle of the disc. Here the warp can be regarded in some sense as an $m=1$ perturbation which can then propagate through the disc as a wave. In addition the tilt drives resonant vertical shear within the disc locally, upon which a small local viscosity can act, or which may itself be subject to shear instability. However, the real interest lies with strongly warped discs, which are of course those whose warps are detectable in some way by astronomical means. Here, the fluid dynamics is strongly non-linear and hard to calculate. Some progress has been made by some participants in treating such discs with smoothed particle hydrodynamics. The simulations indicate propagation of bending waves and show that diffusion of warps can occur much faster than by assuming the rate given by shear viscosity or the mass accretion rate.

Narrow planetary rings are often observed to be non-circular, exhibiting sometimes $m=1$ (eccentric ring) or $m=2$ distortions. This phenomenon can occur because the action of viscosity through the shear can destabilise non-axisymmetric density waves or modes (viscous overstability). Another possible cause is parametric instability induced by a tidal interaction with a companion satellite.

Such phenomena may also occur in larger-scale gaseous discs where viscosity may also excite eccentricity rather than cause it to decay, and a combination of tides and parametric instability has been postulated as causing eccentricity in dwarf novae discs. However, the conditions required for these instabilities, which must depend on the form of viscosity, are poorly understood. There was an opportunity for cross-fertilisation between the two areas of planetary ring dynamics and accretion discs so that, as a result of future collaborations, we might expect a better understanding of the conditions required for viscously-driven non-axisymmetric distortions to occur in discs.

3) Disc interaction with external forces

We remarked above that discs can become non-planar and/or eccentric due to interaction with external constraints. For example, in the protostar field it is known that most stars have binary companions and that star form in crowded regions. Thus a protostellar disc is likely to be subject to interaction with a companion or even a passing interloper. Furthermore it is possible that when two stars come together to form a binary star, there can also be an exterior protostellar disc surrounding the binary system as a whole. What is of interest dynamically in such cases, is not just the result of this interaction on the disc, but also the back reaction of the interaction on the orbits of the stars themselves. If the discs contain sufficient mass, then the orbits of the stars can be severely affected. In particular an exterior disc around a binary system is capable of either increasing or decreasing the eccentricity of the binary orbit, depending on the details of the interaction, and on which resonances come into play in the disc.

Phenomena of this kind occur in most disc situations. In AGN the discs are believed to be fed by a surrounding star cluster with stars spiralling inwards to interact tidally with the disc. In addition these systems have been postulated to contain binary black holes where the partners have comparable mass. In this situation the tidal effects would be similar to those expected in protostellar or stellar discs. There would be important consequences for the accretion phenomenon.

In planetary rings orbiting satellites are seen to cause gaps and shepherd rings. In addition density waves are excited by tidal interaction which are observed to propagate into the disc. These phenomena are also expected to occur in other discs where the excited waves may induce angular momentum transport. Furthermore in the planetary ring case there are many small satellites orbiting within the rings which may be too small to cause gaps. The dynamics in this situation is similar to what is expected when protoplanets form inside protostellar discs. There one is interested in the flow dynamics, possible disc formation about, and observational consequences of accretion onto, the protoplanet. There was an opportunity for cross-fertilisation between planetary ring and accretion disc dynamics. Some work on the problem of gap formation and limitation of accretion onto protoplanets was carried out by some of the participants who were able to compare their latest results.

Organisation

The overall organisation was undertaken by JCB Papaloizou, JE Pringle, J Goodman, and JA Sellwood. Day to day matters were dealt with by J Papaloizou.

The informal colloquia held regularly on Mondays were organised by J Sellwood. The more formal colloquia held on regularly on Thursdays were organised by J Pringle. All four organisers played a significant role in organising the April workshop and the EC summer school.

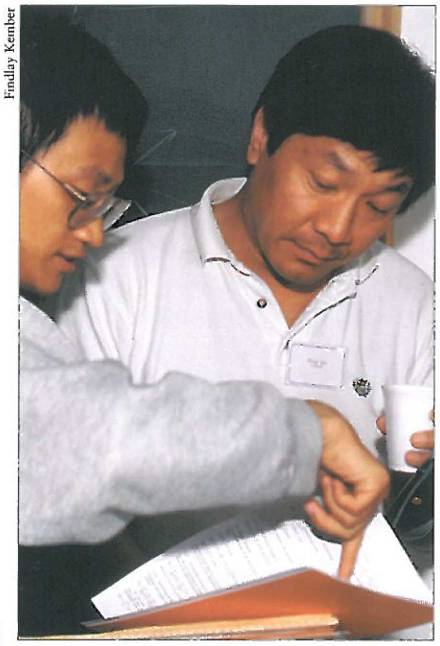
Jerry Sellwood

Findlay Kember

The organisation of the programme was greatly facilitated by the dedicated, helpful and cooperative work of all of the staff at the institute. Without this the programme could not have succeeded.

Participation

The programme attracted 39 long-to medium-term participants staying for periods ranging from 15 days to the entire programme. In addition there were 52 short term participants. During the April workshop, 55 researchers took part and during the EC summer school there were 87 participants, including 26 young researchers funded by the EC.



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Young researchers at the EC Summer School

Practically all of the leading theorists and applied mathematicians interested in accretion discs took part in the programme. The programme had participants from the US, Canada, Europe, the former Soviet Union, South America and the Middle East. Support from the Leverhulme Trust in particular enabled us to invite researchers from Eastern Europe, the former Soviet Union and South America.

Younger researchers were enabled to attend through the junior membership scheme. This was directed towards PhD students in particular.

Special efforts were made to involve UK researchers throughout the country. Overall participation was at the 30 percent level. The April workshop specifically had UK review speakers wherever possible.

Meetings and Workshops

We had two long workshops. These were as follows:

Workshop on Discs in Astrophysics, April 6-8 1998
This workshop was directed towards advanced graduate students, postdoctoral fellows and researchers and was intended to bring together scientists interested in physical processes that occur in Astrophysical Discs. Special efforts were made to involve UK participants, both as review speakers and participants with the object that they should be able to take advantage of the opportunity to meet and interact with the international programme participants. The topics focused on were: hydromagnetic processes, turbulence, and external forcing as they applied to discs in the contexts of active galactic nuclei, galaxies, protostars and close binary systems.

The Organising Committee consisted of J Goodman (Princeton), J Papaloizou (London), J Pringle (Cambridge), and J Sellwood (Rutgers). Review speakers included: J Binney (Oxford), A Brandenburg (Newcastle), C Gammie (Harvard), J-P Lasota (Paris), G Ogilvie (Cambridge), C Parnell (St. Andrews), S Sridhar (Pune), A Whitworth (Cardiff), G Wynn (Leicester).

Jim Pringle

Findlay Kember

Many young researchers attended and presented posters at the meeting.

EC Summer School, 22-27 June 1998: Astrophysical Discs
This school was held at the end of the programme with the object that the lecturers, most of whom were participants, should combine material they had been working on during the programme with a general review of the topic they were lecturing on. Overall a summary of the work undertaken during the programme would then appear in the context of the background of the field.

The Lecturers were: T Marsh (Southampton), F Verbunt (Utrecht), J Hawley (Virginia), J Sellwood (Rutgers), A Toomre (MIT), A Fridman (Moscow), C Chandler (Cambridge), P Armitage (Toronto), M Livio (Baltimore), C Gammie (Harvard), J Pringle (Cambridge), G Ogilvie (Cambridge), J Papaloizou (London), C Terquem (Santa Cruz), J Leahy (NRAL), L Tacconi (MPI), R Blandford (Caltech), I Yi (IAS), P Natarajan (Toronto), R Pudritz (McMaster), E Ostriker (Maryland), D Lin (Santa Cruz), A Toomre (MIT), P Nicholson (Cornell), S Sridhar (Pune), L Sparke (Wisconsin-Madison), R Nelson (QMW), G Laughlin (Berkeley), L Athanassoula (Marseille).

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Poster session at the EC Summer School

The school attracted around 40 young researchers, many of whom presented posters on their most recent work.

Throughout the programme an informal seminar series was held on Monday mornings. This was used as a mechanism for recently-arrived participants to present their most recent work and obtain feedback from the other participants.

In addition to these a more formal series was organised on Thursdays. The object here was to invite a speaker with an observational bias to give a talk and then to stay over for a few days to interact with the more theoretical participants, so providing a direction for their researches. Speakers included K Horne (St Andrews), A Kinney (Baltimore), A Fabian (Cambridge), M Stills (St Andrews), J Bouvier (Grenoble).

Outcome and Achievements

The main achievement of the programme was that it brought together researchers from widely different backgrounds in astrophysics and enabled them to interact in a good atmosphere for a long period in a situation they would be unlikely to find themselves in otherwise. The programme concentrated on younger researchers at their most productive stage and was instrumental in producing an environment in which new and potentially important collaborations were begun. It is difficult at this stage to predict the final outcome but it is likely that there will be important progress in the three areas that the programme focused on. An outline of the activities of some of the participants carried out at the institute is given below.

J Goodman made progress in constructing more accurate self-similar solutions for non axisymmetric waves in self-gravitating discs and also on the theory of the stability of such discs together with N Evans. J Goodman, C Gammie and G Ogilvie studied parametric instabilities of vertical shearing motions in discs. These might lead to turbulence and anomalous viscosity which might damp warps. R Nelson, J Papaloizou and C Terquem studied bending waves and warps in discs using smooth particle hydrodynamics simulations. These enable calculation of the Bardeen-Petterson radius in the low viscosity regime. C Terquem, R Nelson, J Goodman and J Papaloizou compared results of tidal circularisation timescale calculations for a solar mass star. P Maloney, C Terquem, and J Papaloizou began a project to study the effect of density waves controlled by self-gravity on the possible radiation driven warping of discs. S Balbus and C Terquem begun a collaboration related to applying the new results of MHD simulations to observed protostellar discs. S Balbus and J Papaloizou began a collaboration on the stability of magnetised disks. J Sellwood and S Balbus collaborated on the application of MHD instabilities to galactic discs. A Brandenburg began projects with H Spruit, J Goodman and E Agol on the decay of vortical structures and passive vector fields in a turbulent disc. C Campbell and J Papaloizou began a study of the application of mean field dynamo theory to the problem of magnetic field dragging through discs. A Kinney, H Schmitt, and J Pringle worked on a statistical study of the jet orientation in Seyferts relative to the host galaxy. This study holds the promise of interesting future results which may relate to the underlying disc dynamics. R Stehle, J Larwood and M Tagger began a collaboration aimed at studying the properties of eccentric discs in binary systems. An important and up-to-now neglected aspect is to compare the performance of Lagrangian particle based schemes and finite difference grid based schemes. D Syer, J Touma, and S Sridhar collaborated on making self-consistent models of eccentric discs comprising stars in near Keplerian potentials. Such a disc may exist in the centre of the galaxy M31 but a self-consistent model has yet to be made and progress towards one has been made at the Institute.

Findlay Kember

John Papaloizou

Arithmetic Geometry (January to June 1998)

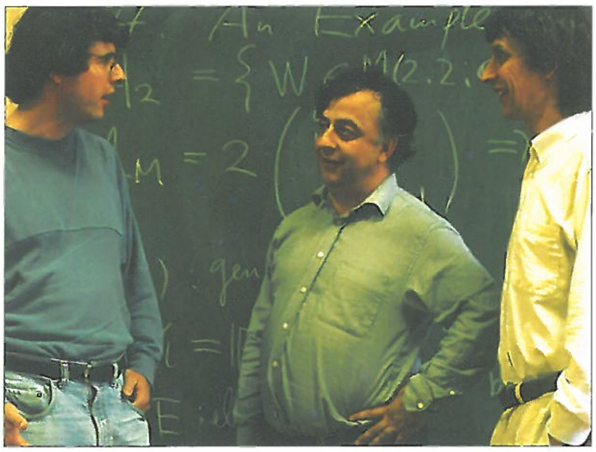
Report from the Organisers:

J-L Colliot-Thélène (Orsay); J Nekovář, (Cambridge); C Soulé (IHES)

One of the origins of Arithmetic Geometry is the study of diophantine equations, where the goal is to solve polynomial equations in integers or rational numbers. The simplest example (going back at least to the Babylonians) involves rational solutions of $x^2 + y^2 = 1$. They correspond to right-angled triangles in which all sides have integral length (such as (3,4,5) or (5,12,13)). In this case the set of all solutions can be described explicitly; either in terms of geometry of the circle, or by a simple formula involving complex numbers.

The interplay between algebra, number theory and geometry which is characteristic of the subject was anticipated already in the middle of the 19th century. Kronecker's vision of a unification of number theory and algebraic geometry had never been completely forgotten, but it came fully into life only after Grothendieck's revolution in algebraic geometry in the 1960s. One of the most spectacular developments has been the introduction to the subject of topological invariants that combine very subtle arithmetic and geometric information. Another important feature has been the growing importance of analytic methods, such as techniques from transcendence theory or hermitian geometry.

Arithmetic geometry is a vast subject. The programme concentrated on the following areas: arithmetic of algebraic cycles, motives and motivic cohomology, diophantine geometry, Arakelov geometry, values of L-functions. Other areas, such as modular forms and p-adic methods, were given lesser prominence, because of recent programmes at the IAS in Princeton and Centre Émile Borel in Paris that were devoted to them.



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J Nekovář, C Soulé and J-L Colliot-Thélène

Seminars

There were regular seminars on Tuesdays and Wednesdays, which gave participants an opportunity to speak about their work. Some of the Wednesday seminars were more specialised. In January and February there was a series of talks devoted to the work of Voevodsky and Suslin. In May and June there were seminars on the Gross-Zagier formula and its generalisations, with four lectures by S Kudla providing the main focus.

Meetings

Arithmetic of Algebraic Cycles and Motivic Cohomology, 23-27 February, 1998

This workshop was organised by J-L Colliot-Thélène and U Jannsen. It was attended by about 60 participants from the following countries: Canada, France, Germany, India, Italy, Japan, Netherlands, Poland, Russia, Spain, Sweden, Switzerland, UK and USA.

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Participants at the February workshop

Special Lectures on Applications of Model Theory to Diophantine Geometry, 17-19 March, 1998

This series of lectures was organised by A Pillay. The speakers were A Macintyre, A Pillay and T Scanlon. The main goal was to make a contribution to the growing interaction of model-theorists and algebraic/arithmetic geometers. The talks by Pillay and Scanlon gave an exposition of Hrushovski's work (and of their own contributions) on the Mordell-Lang conjecture for function fields in positive characteristic. Macintyre's talk was concerned with the model theory of the nonstandard Frobenius.

EU Summer School: Arithmetic Geometry

This two-week Summer School was supported by the European Union, the Leverhulme Foundation and the Isaac Newton Institute.

Part I: Instructional Conference, Current Trends in Arithmetical Algebraic Geometry, 23-28 March, 1998
The goal of this instructional conference was to bring the audience of predominantly young researchers (postdocs and PhD students) in direct contact with some of the most important current research. There were four lecturers, A Goncharov (*Polylogarithms, regulators, values of L-functions*), M Nakamaye (*Diophantine approximation on algebraic varieties*), P Salberger (*Manin's conjecture on points of bounded height*) and V Voevodsky (*Motivic homotopy theory*), each giving 4-5 one-hour lectures. While these talks presented very advanced and recent material, the speakers succeeded very well in presenting it with enough details and preliminaries, so that the large and uneven audience would catch most of what was said. The organisers encouraged all participants to ask questions, and, indeed, there were many, both during the lectures and at the end of them. Notes had been written by the speakers prior to the meeting, and they were widely distributed. There were about 80 participants, from Austria, Bulgaria, Czech Republic, France, Germany, India, Italy, Netherlands, Russia, Spain, Sweden, UK and USA.


Neville Taylor

Young participants at the EC Summer School

Part II: Rational Points, 29 March - 3 April, 1998
This was a combination of a research and a survey conference, organised by J-L Colliot-Thélène and P Swinnerton-Dyer. The general aim of the conference was to give the participants a global view of what is known and what is to be expected of rational points, depending on the place of varieties in the geometric classification. There were about 100 participants, from Austria, Belarus, Bulgaria, Croatia, Czech Republic, France, Germany, Hungary, India, Israel, Italy, Netherlands, Russia, Spain, Sweden, Switzerland, UK and USA.

Computational Results in Arithmetic Geometry, 14-16 April, 1998
This workshop was organised by N Smart and N Stephens. It was attended by 54 people from the following countries: France, Germany, Hungary, Italy, Japan, The Netherlands, Spain, Sweden, UK, USA. There was a large contingent from the UK, including a number of PhD students.

Arakelov Theory, Values of L-Functions, 29 June - 3 July, 1998
This workshop was organised by J Nekovář and C Soulé. The goal was to describe new developments in Arakelov theory and to discuss recent advances relating this field to values of L-functions. There were about 80 participants, from France, Germany, India, Israel, Italy, Japan, Poland, Romania, Russia, Spain, Sweden, Switzerland, UK and USA.

The programme and its achievements

The rest of the report describes the topics covered by the programme and some of the concrete results obtained by the participants during the programme or shortly afterwards. One of the main goals of the programme was to reflect the diversity of the subject (with limitations alluded to in the Introduction) and at the same time concentrate on areas of high research activity. Roughly speaking the programme consisted of three periods of two months length. Each period had a different focus, even though there were some overlaps between them.

The First Period

The first two months of the programme and the first workshop were devoted to arithmetic of **algebraic cycles, motivic cohomology** and related topics.

A fundamental problem of algebraic geometry is a description of all subvarieties of a given algebraic variety, eg of all algebraic curves on a given surface. Over complex numbers, this appears to be a purely geometric problem. Over the field of rational numbers Q the question also involves arithmetic. In its full generality the problem is completely intractable. However, one can introduce a linearised version of the problem, which is hopefully more accessible. The simplest example is that of points on curves. An *elliptic curve* E is given in affine coordinates by an equation

$$E : y^2 = x^3 + ax^2 + bx + c.$$

The set of solutions (x,y), together with the unique point 0 at infinity, has a natural structure of an abelian group (three intersection points of E with any line add

One of the most surprising recent developments in this area is due to E Hrushovski, who proved deep results in diophantine geometry over function fields using methods of model theory. As part of the programme, A Pillay and T Scanlon gave a series of lectures on Hrushovski's work and its generalisations. A similar but slightly different gathering of logicians and number theorists occurred a few months earlier at the MSRI in Berkeley. There appears to be a genuine interest on both sides to pursue this mutually beneficial interaction of the two fields.

A topic much discussed during the second part of the programme was the Hasse principle, together with the related problem of weak approximation.

Descent for open varieties was used by J-L Colliot-Thélène and A Skorobogatov who investigated varieties fibered over a projective line in the case when the principle is known for its fibres and the number of "bad" fibres is small. The Hasse principle can fail even in families of varieties; J-L Colliot-Thélène and B Poonen constructed one-parameter families of principal homogeneous spaces under abelian varieties such that each fibre over a rational point of the base is a counterexample to the Hasse principle. R Heath-Brown completed his work on the solubility of diagonal cubic diophantine equations $\sum p_i x_i^3 = 0$ (where p_i, $i = 1, \ldots, 4$ are prime numbers congruent to 2 modulo 3). He showed that there is always a non-trivial rational solution, assuming Selmer's parity conjecture (itself a consequence of the finiteness of the

Obstructions to the Hasse principle

Is there an elementary criterion for solvability of (certain classes of) diophantine equations? More than 200 years ago, Legendre showed that the diophantine equation

$$ax^2 + by^2 + cz^2 = 0 \quad (*)$$

(where a,b,c are non-zero integers) has a solution in integers x,y,z not all zero whenever the obvious necessary conditions are satisfied. The obvious conditions are that a,b,c be not all of the same sign (so that there is a nontrivial solution in the real numbers) and that all the congruences

$$ax^2 + by^2 + cz^2 = 0 \pmod{p^n}$$

(p a prime number, $n \geq 1$) have primitive solutions (i.e. with at least one of x,y,z prime to p). Following Hensel, we can rephrase these necessary conditions in a more concise fashion: the equation (*), which defines a non-singular conic over the field of rational numbers Q, should have non-trivial solutions in all completions of Q, namely in the real field and in the p-adic fields Q_p. Legendre's result was generalised to quadratic equations in any number of variables over Q and over arbitrary number fields by Minkowski and Hasse, respectively.

Since then, similar local-global results were proved for many algebraic varieties (= systems of polynomial equations), most of them homogeneous spaces of linear algebraic groups. However, it was recognised already in the 1930s that such a local-global principle ("Hasse principle") for the existence of rational points did not apply to all algebraic varieties. Among various counterexamples given over the years, perhaps the simplest one is due to Selmer: the equation

$$3x^3 + 4y^3 + 5z^3 = 0$$

has non-trivial solutions in all completions of Q, but not in Q itself.

In 1970, Manin proposed a general algebraico-geometric interpretation: most of these counterexamples to the Hasse principle could be accounted for by the existence of non-trivial elements in the Grothendieck-Brauer group of varieties in question, together with the famous reciprocity law of class field theory. Is this obstruction of Manin to the Hasse principle for the existence of rational points the only one for all nonsingular algebraic varieties? It was shown in the 1980s that this was indeed the case for certain special classes of varieties, most of them unirational. More recently, conditional results assuming various well-known but daring conjectures were obtained for interesting classes of surfaces, including some surfaces given by equations

$$a_0x_0^4 + a_1x_1^4 + a_2x_2^4 + a_3x_3^4 = 0 \quad (**)$$

For more general varieties one expected counterexamples, but it was only in 1997 that Skorobogatov found one that did not appeal to any conjectures. This is a (hyperelliptic) surface over the rationals, given by the system of affine equations

$$(x^2+1)y^2 = (x^2+2)z^2 = 3(t^4-54t^2-117t-243) \quad (***)$$

The search for a general theory behind this example is one of the directions where some progress was achieved during the programme.

Tate-Šafarevič group of elliptic curves). He proved similar conditional results for equations in five variables. Conditional results on the Hasse principle for surfaces of the form (**) were obtained by R Pinch and P Swinnerton-Dyer, who assumed the finiteness of the Tate-Šafarevič group and Schinzel's hypothesis. The method uses explicit 4-descent and has numerical applications. In the first three works mentioned, the Brauer-Manin obstruction is the only obstruction for the existence of rational points. Whether or not this is the case in the fourth work has not yet been clarified but it is quite likely. A new proof of the Hasse principle for quasi-split algebraic groups over number fields was given by P Gille. During his stay at the Newton Institute, A Skorobogatov completed his work related to the example (***). This work was taken up by D Harari, who devised a rather systematic way of producing varieties with rational points for which weak approximation fails, but for which the Brauer-Manin obstruction is not enough to prove this. The varieties have non-abelian fundamental groups; this is the key point, and it also seems to be the key to Skorobogatov's example.

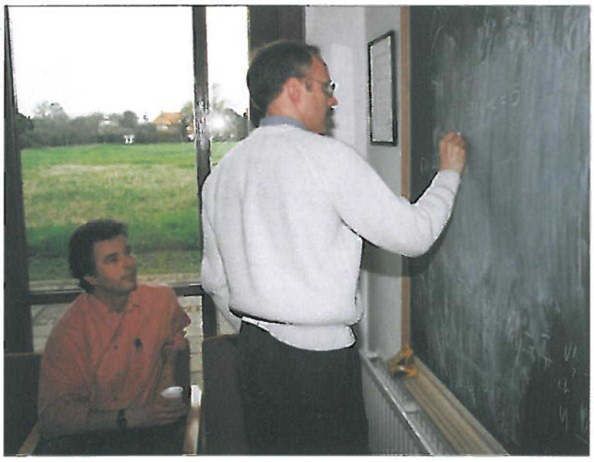
Another topic involved counting points of bounded height. The height of a rational point is, roughly speaking, equal to the maximum number of digits in the numerators or denominators of its coordinates. At the end of the 1980s, a new research programme was started by Manin and his collaborators. Partly on the basis of numerical evidence, partly out of a belief in the power of geometry, they conjectured that if a Fano variety possesses rational points, then the number of rational points of height at most H and located away from a certain exceptional subvariety behaves like $CH(\log H)^{t-1}$ when H grows. Here $C > 0$ is some constant and $t \geq 1$ is the rank of the Picard group of the variety. (A classical example is that of projective space, other examples include more general homogeneous spaces.) The constant C was made precise by Peyre (using a Tamagawa measure on adelic points), a factor was added later by Batyrev and Tschinkel, who proved the conjecture for toric varieties and disproved it for general Fano varieties. For important classes of varieties, such as cubic surfaces, the conjecture is still open. One important new aspect in the theory is the introduction of universal torsors by Peyre and by Salberger, independently.

At the Instructional Conference in March, P Salberger gave a series of lectures on Manin's conjectures. While at the Institute, he completed a long paper describing his point of view on the use of universal torsors, in particular for (split) toric varieties, where he can prove the conjectures in a manner completely different from that of Batyrev/Tschinkel. E Peyre reformulated the classical circle method from analytic number theory from the point of view of universal torsors - this provides a good control of what should be the main term in the estimates. E Peyre and Yu Tschinkel gave a description of Peyre's constant (multiplied by the factor found by Batyrev and Tschinkel) in a manner suitable for explicit computations. This enabled them to produce more numerical evidence on the asymptotic growth of the number of rational points on diagonal cubic surfaces.

The Rational Points Conference (second part of the EU Conference) was one of the highlights of this Period. According to the geometric point of view taken on rational points, it started with a survey talk (by A Corti) on the Mori programme of classification of varieties over algebraically closed fields. It then went on to consider the properties of points of varieties according to their place in the classification.

A) Rational points on varieties of general type: There were talks on the connection between the Lang conjecture and uniform upper bounds in the Mordell conjecture (Abramovich), an Arakelov version of the Masser-Wüstholz proof of Faltings' isogeny theorem (Bost), the *abc* conjecture for affine open sets of an abelian variety (Buium), a survey on the product theorem and related topics (Faltings), Nevanlinna theory and Vojta's conjectures (McQuillan), effective determination of rational points on curves of genus at least two (Poonen) and a strong form of the *abc* conjecture (Vojta).

Neville Taylor



F Beukers, P Vojta and the *abc* conjecture

B) Curves of genus one and families of curves of genus one: Along with talks by Heath-Brown, Skorobogatov and Swinnerton-Dyer on topics mentioned earlier on, there were talks on bounds for torsion on elliptic curves (Merel), elliptic curves with high ranks (Mestre) and the average rank of a one parameter family of elliptic curves (Silverman).

C) Counting points of bounded height on Fano and similar varieties: There were talks on various aspects of Manin's conjectures (Peyre, Strauch, Tschinkel).

D) Qualitative aspects: Various aspects of the Brauer-Manin obstruction appeared in several talks (Harari, Skorobogatov, Swinnerton-Dyer); other topics included integral points on quotients of affine spaces by finite groups (Beukers) and rational points on certain moduli spaces (Shepherd-Barron).

Neville Taylor

J Silverman, J Cremona and B Birch at the Rational Points Conference

The meeting on *Computational Results in Arithmetic Geometry* was focused on explicit algorithms. There were talks on a variety of topics ranging from theoretical work on modular curves through to applications in cryptography. Of particular benefit was the timely coming together of the main researchers in the field of algorithms to find rational points on curves of genus greater than one. There has been much progress in recent years on this topic and a number of lectures discussed the various approaches to the problem.

In this more explicit direction, F Beukers and C Smyth worked on effective computation of torsion points lying on subvarieties of tori.

The Third Period

The last two months of the programme and the final workshop were devoted to **Arakelov theory and values of *L*-functions.** What is Arakelov theory about? In the analogy between number theory and geometry, the ring of integers $\mathbf{Z} = \{ 0, \pm 1, \pm 2, \ldots \}$ is very close to the polynomial ring $\mathbf{C}[X]$ in one variable over complex numbers. Geometrically, $\mathbf{C}[X]$ is the ring of functions on the affine line $\mathbf{A}^1_{\mathbf{C}}$ over $\mathbf{C}$ and $\mathbf{Z}$ is the ring of functions on another one-dimensional object called Spec($\mathbf{Z}$). The projective line $\mathbf{P}^1_{\mathbf{C}}$ over $\mathbf{C}$ is obtained from $\mathbf{A}^1_{\mathbf{C}}$ by adding one point at infinity. Existence of an analogous point at infinity for Spec($\mathbf{Z}$) was well understood already in classical algebraic number theory. Around 1970, Arakelov considered the projective line $\mathbf{P}^1_{\mathbf{Z}}$ over $\mathbf{Z}$. This is an archetype of an arithmetic surface - a two-dimensional object with one dimension of arithmetic nature (as in Spec($\mathbf{Z}$)), the other one geometric. Arakelov discovered that by adding to $\mathbf{P}^1_{\mathbf{Z}}$ a copy of $\mathbf{P}^1_{\mathbf{C}}$ at infinity one gets an arithmetic object very close to the projective plane $\mathbf{P}^2_{\mathbf{Z}}$ over $\mathbf{C}$. For example, two curves of degrees m resp. n in the projective plane intersect at exactly mn points (counting multiplicities). Arakelov developed similar intersection theory on any compactified arithmetic surface; the contributions from infinity were computed using Green's functions, ie fundamental solutions of the Laplace equation. In the 1980s, Arakelov intersection theory was generalised to arbitrary dimensions by Gillet-Soulé and others. A general arithmetic Riemann-Roch theorem was proved. Subsequently this geometry was used in the proof of important diophantine results, for example in the proofs by Faltings and Vojta of finiteness theorems for rational points on subvarieties of abelian varieties. A couple of years ago, another diophantine result was proved by Ullmo and Zhang: the Bogomolov conjecture, according to which algebraic points of a curve of genus greater than one are discrete in the Jacobian equipped with the Néron-Tate topology.

Apart from an opportunity for newcomers to the field to meet for the first time, the goal was to investigate a new direction for Arakelov theory, namely its link to modular forms and values of *L*-functions. It has been noticed for some time that the Mahler height of certain polynomials can be expressed as a value of an *L*-function (Smyth, Deninger). Also, the celebrated theorem of Wiles suggests the study of Arakelov invariants of modular curves in order to understand arithmetic of elliptic curves. The self-intersection of the relative dualising sheaves of modular curves has been computed by Abbès, Ullmo and Michel. Last year, Bost, Kühn and Kramer computed a similar quantity for the universal family of elliptic curves over a modular curve. These last computations appear to be related both to the arithmetic Riemann-Roch theorem (with singularities) and to the famous *Gross-Zagier formula*, which expresses the height of Heegner points on a modular curve as a value of (the derivative of) its *L*-function. So there is hope that the two topics can be


Findlay Kember

S Kudla, M Rapoport and A Goncharov

related. A special seminar was devoted to the Gross-Zagier formula. After introductory talks, a series of lectures by S Kudla gave an overview of "Kudla's programme", the aim of which is to provide a conceptual approach to the Gross-Zagier formula and its higher dimensional generalisations. S Zhang presented his work on the higher weight version of the formula. R Borcherds gave a lecture on his new approach to a theorem of Gross-Kohnen-Zagier about the relative position of Heegner points in the Jacobian of a modular curve and its generalisation to higher dimensions.

In the subject of values of L-functions the goal is to "explain" certain naturally occurring numbers, such as $1 + 2 + 3 + \ldots = -1/12$ or $1 + 1/2^4 + 1/3^4 + \ldots = \pi^4/90$. Deep conjectures of Beilinson and Bloch-Kato predict that these values are closely related to the structure of the category of mixed motives and to motivic cohomology, with the link provided by regulator maps or height pairings. The Gross-Zagier formula is a typical example of this phenomenon. There has been a growing interest in explicit constructions of elements in motivic cohomology and of regulator maps. A whole new industry of "polylogarithms" is involved in this enterprise. The name comes from close links to Euler's polylogarithm functions $Li_m(z) = \Sigma_{k\geq 1} z^k/k^m$.

An introduction to the whole circle of ideas around polylogarithmic complexes, their conjectural relation to motivic cohomology and values of L-functions was given by A Goncharov in his lectures at the Instructional Conference. He also presented an explicit construction of regulator maps on the level of Bloch's complexes representing higher Chow groups. While at the Institute, A Goncharov continued his work on "higher cyclotomy" - the values of multiple polylogarithms at roots of unity and their mysterious relations to modular forms. J Tate formulated a generalisation of B Gross's conjecture on refined special values of Artin's L-functions and their derivatives. A few weeks later, D Burns showed that Tate's conjecture is a consequence of equivariant Bloch-Kato conjectures. A surprising link between epsilon constants (long studied by specialists in the Galois module structure) and Arakelov-type invariants was discovered by M Taylor, B Erez and their collaborators. They had discussions with C Soulé on the subject. A Riemann-Roch Theorem in the context of non-archimedean Arakelov theory was proved by H Gillet and C Soulé. They also found a better proof of a comparison between two spectral sequences in algebraic K-theory. The non-archimedean Arakelov theory was also used by K Künnemann to define local heights for cycles on abelian varieties. Furthermore, he started a collaboration with H Tamvakis in order to prove the so called "arithmetic standard conjectures" in the case of Grassmann varieties; even for these simple varieties, these conjectures in Arakelov theory happen to require a very new and difficult combinatorics. Other aspects of the theory, such as p-adic methods, were also represented. Theory of p-adic integration and p-adic regulators was being developed by A Besser and, from a slightly different perspective, by P Colmez. A first complete account of K Kato's results on Euler systems for modular forms of weight 2 was written down by A Scholl, who put together scattered fragments of Kato's lectures and filled in all technical details. J Nekovář generalised his earlier results on syntomic regulators to the case of semistable reduction. He also continued to develop the theory of Selmer complexes, including duality theory, p-adic heights and Iwasawa theory for certain families of Galois representations.

The interaction between Arakelov theory and values of L-functions was at the heart of the final meeting, together with new developments in the first (equivariant Arakelov theory, singular metrics) and the second topic (order of vanishing of L-series at the centre of symmetry). There were three lectures on different aspects of a generalised Gross-Zagier formula (Rapoport, Tipp, Zhang). Other links between these two theories appeared in several lectures, eg in a new definition of Borcherds' new modular forms on the moduli space of $K3$-surfaces in terms of Quillen metrics instead of infinite products (Yoshikawa), or in the interpretation of the epsilon constants in terms of these metrics (Chinburg, Taylor *et al*). Similar links appeared elsewhere in the programme: Goncharov's work on regulators led to the definition of higher Arakelov K-theory and Colmez's results on the % Chowla-Selberg formula (proved by Lerch half a century before them) suggested a relation to the arithmetic Riemann-Roch

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S Zhang, K-I Yoshikawa and A Moriwaki

formula. Altogether, the general impression was that much more is to be discovered about the connection between the two fields.

Conclusion

Arithmetic Geometry is well and alive. It involves both beautiful general theories and a flurry of new methods, questions, and results. The programme reflected this diversity. It was also a unique occasion for many participants to start new and unexpected collaborations that will, hopefully, bear fruit in the future.

Mathematics of Atmosphere and Ocean Dynamics Review Meeting held 1-5 December, 1997

Report from the Organiser:

Ian Roulstone (UK Meterological Office)

This meeting attracted about 30 participants, many of whom had taken part in the AOD programme (*Mathematics of Atmosphere and Ocean Dynamics*) from July to December, 1996. The original programme stimulated many new directions of research and triggered informal collaborative projects, and it was therefore timely to provide a forum for reviewing progress over the subsequent 12 months or so.

The scope of the presentations was very broad, ranging from hamiltonian fluid mechanics and balanced models to mesoscale meteorology and parameterisation schemes. During the first two days discussions on recent results on integrability, turbulence, and regularity of solutions of balanced models, predominated. The generation of small scales in the enstrophy in two-dimensional incompressible flow can be understood using the analytical tools which are used to prove existence and regularity of results for these equations. Many important issues relating to the enstrophy cascade in semi-geostrophic turbulence, and in the solutions of more general systems of equations, were discussed.

The theory of optimal mass transfer featured in several talks. The basic problem is as follows: given two sets of equal volume, find the optimal volume-preserving map between them, where optimality is measured against a cost function. Such problems arise when studying the semi-geostrophic equations. Recent research has focused on regularity theory, and existence of optimal mappings when the sets are replaced by manifolds. This is relevant to semi-geostrophic theory, and computations involving optimal transport were also presented.

Wednesday and Thursday had a slightly more geophysical theme, including some recent numerical results on predictability and growing normal modes, and numerical methods for the semi-geostrophic equations. Discussions also took place on sub-grid models and their interaction with resolved dynamics.

We were pleased to welcome several people who did not participate in the AOD programme in 1996, but have been involved in related work. Among those were Robert McCann (Brown), who spoke about free boundaries and discontinuities in optimal transport, Jean-David Benamou (INRIA), who spoke on the numerical resolution of the mass transfer problem based on an augmented lagrangian technique and also presented some numerical results, and Emmanuel Grenier (Paris VI), who gave a presentation on a new approach, from a pde point-of-view, to the derivation of the quasi-geostrophic and semi-geostrophic equations.

Overall, this meeting was a very worthwhile exercise which has, in turn, stimulated further collaboration and research. It was noted that a number of symposia at international conferences have been based around work emerging from the AOD programme.

Fletcher Morgan

First-day speakers at the review meeting: (left to right) Edriss Titi, Robert McCann, Yann Brenier, Darryl Holm, Mike Cullen

Management

Management Committee

The members of this committee as at 30 June 1998 were:

Professor Sir Martin Rees FRS (Chairman)	CSPS, Cambridge
Professor HK Moffatt FRS (Director)	Newton Institute
Dr N Linden (Secretary, Deputy Director)	Newton Institute
Dr CT Sparrow (Liaison Officer)	Mathematics Faculty
Professor A Baker FRS	Trinity College
Professor J Brindley (co-opted)	Leeds
Professor DG Crighton FRS	DAMTP, Cambridge
Professor EB Davies FRS	KCL (LMS representative)
Professor AP Dowling	Engineering, Cambridge
Professor FP Kelly FRS	Statslab, Cambridge
Professor WBR Lickorish	DPMMS, Cambridge
Dr A Rose	EPSRC
Professor GB Segal FRS	St John's College
Professor Sir Christopher Zeeman FRS	Oxford

During this year Dr G Richards (EPSRC) and Professor D Brannan (Open, LMS representative) also served as members of the committee.

The committee met four times during 1997/98 on 13 October 1997 (Extraordinary Meeting), 25 November 1997, 2 March 1998 and 22 May 1998.

The Management Committee's job is to oversee the organisational and practical aspects of the Institute's operations. Its rôle is complementary to that of the Scientific Steering Committee (indeed, the division of responsibility between the two bodies resembles that between the Programme Committee and Local Organising Committee for academic conferences).

A comparison with similar institutions around the world shows that the Newton Institute is exceptional because of its very broad scientific remit (mathematics and all its applications) and its diversity of funding. Despite its modest size and resources, the Institute has already had an impressive impact, in the UK and internationally, over a very wide scientific community. There will always be more excellent proposals than can be accommodated. The Institute's goal is therefore to maximise its level of activity and enable as many people as possible to participate either as long-term participants in its programmes, or by attending workshops and schools. The very large 'throughput' of participants from all over the world obviously imposes pressures on the organisation which are very different from those in most academic institutions. The last year has seen a vibrant and wide-ranging programme, and also gratifying initial steps towards establishing the endowment that the Institute needs to ensure its long-term future.

These successes owe a great deal to Keith Moffatt's dynamic leadership, and to the Deputy Director, Noah Linden; the administrative staff, led by Ann Cartwright, deserve our thanks for the effective and friendly way the Institute operates. All of us remain receptive to suggestions for further improving and developing the Institute's role, and are committed to ensuring that it plays a cost-effective part in strengthening the UK's impact in the mathematical sciences.

Martin Rees
Chairman, Management Committee

Financial and Fund-raising

The Institute was successful in fund-raising in 1997/98 from the following organisations:.

EPSRC: A Panel visited the Institute in December 1997 to review its work and make recommendations about its future. As a result of this, the Institute's rolling grant was extended until February 2002. The award was £1 million for travel and subsistence for the four-year period March 1998 to 28 February 2002 and £1.4 million for scientific and administrative salaries for the same period. Discussions are in progress concerning possible modes of funding for the Institute beyond 2002.

PPARC: PPARC assessed the Institute independently for the first time in 1997 and, as a result, it too extended its rolling grant to February 2002, at the level of £240,000 for the same four-year period.

NM Rothschild and Sons: An important donation was given by NM Rothschild and Sons: £1.75 million by deed of covenant over five years to endow a new Professorship of Mathematical Sciences, the holder to be concurrently Director of the Newton Institute. An event to mark this gift was held on 4 June 1998 (see p4 above).

Hewlett-Packard: HP agreed in principle to renew its funding to the Institute for the support of a Hewlett-Packard Senior Researcher for a further 5 years from August 1999, details yet to be finalised. The present Hewlett-Packard Reader in Quantum Mechanics is Dr Sandu Popescu. HP has also informally agreed to a programme of renewal of HP computers over the next four years.

Newton Trust: The donation by NM Rothschild and Sons more than meets the main condition imposed by the Newton Trust, that the Institute should raise a matching sum in endowment to that offered by the Trust. The Trustees have therefore agreed that the loan of £1 million may now be converted to endowment.

Leverhulme Trust: Funding from this charitable trust was renewed for a further three years from 1997/98 at the increased rate of £70,000*pa*.

CNRS: The Institute's agreement with CNRS was renewed for a further five years.

LMS: LMS agreed to renew its funding to the Institute, and increased the amount from £10,000*pa* to £15,000 over the two-year period 1997/99.

Silicon Graphics: SGI have agreed a scheme whereby they provide, at nominal cost, up to ten computers which are replaced and upgraded every six months.

Cambridge Philosophical Society: The Society's grant, providing bursaries for young people attending Institute programmes, was increased from £1000*pa* to £2000*pa* in 1997/98 and renewed for five years.

NATO: NATO funded two Advanced Study Institutes at the Newton Institute in this academic year. These were entitled Generalisation in Neural Networks and Machine Learning (4 to 15 August 1997), within the *Neural Networks and Machine Learning* programme and Supersymmetry and Trace Formulae: Chaos and Disorder (8 to 20 September 1997) within the *Disordered Systems and Quantum Chaos* programme.

EC: The EC funded four Summer Schools, one for each programme. These were entitled Disordered Systems and Quantum Chaos; Probabilistic Graphical Models (within the *Neural Networks and Machine Learning* programme); Current Trends in Arithmetic Geometry and Rational Points (Parts I and II of the Summer School for the *Arithmetic Geometry* programme) and Astrophysical Discs (within the *Dynamics of Astrophysical Discs* programme).

Programme Funding: The programmes which took place during this year attracted supplementary funding from British Aerospace, British Airways and Rolls Royce (*Neural Networks and Machine Learning*) and the Thriplow Trust (*Arithmetic Geometry*). In addition, the week-long meeting of those involved with *Mathematics of Atmosphere and Ocean Dynamics* attracted a grant from the Meteorological Office.

Financial Report for 1997/98

Income	96/97	97/98
Grant Income - Revenue	1,487,560	1,382,437
Grant Income - Workshop	228,774	217,845
Donations - Revenue	669	366
Donations - Capital	0	0
General Income	48,975	48,261
Housing	8,604	7,295
Total	**1,774,582**	**1,656,206**

Expenditure		
Scientific Salaries	331,267	322,539
Scientific Travel & Subsistence	423,832	412,831
Scientific Workshop	179,616	182,065
Other Scientific Costs	9,166	13,462
Staff Costs	284,576	264,210
Computing Costs	41,474	65,172
Library Costs	16,208	19,785
Audio-Visual	6,647	3,727
Building - Capital	0	13,870
Building - Rent	184,000	184,000
Building - Repair & Maintenance	14,360	10,907
University Overheads	35,158	35,564
Consumables	49,389	53,271
Equipment - Capital	23,653	1,232
Equipment - Repair & Maintenance	10,009	5,174
Publicity	8,581	10,389
Recruitment Costs	9,153	1,402
Miscellaneous	0	3,324
Reprovision	145,000	80,000
Total	**1,772,089**	**1,682,922**
Income Less Expenditure	2,493	(26,716)

Notes to Accounts

1. Grant Income - Revenue
This breaks down as follows:

	Year 5	Year 6
EPSRC/PPARC Salaries	379,391	375,113
EPSRC/PPARC T & S	249,566	272,627
Newton Trust	212,807	108,267
St John's College	150,000	0
U of Cambridge (Rent)	25,989	184,000
Hewlett-Packard	98,000	98,000
Rothschild	15,788	0
CNRS	44,434	38,589
Rosenbaum	45,095	47,269
Leverhulme	66,907	76,231
Leibniz	22,698	0
Marie Curie Fellowship	0	15,002
Info Systems C'ttee	16,119	0
Royal Society	9,752	8,444
LMS	17,500	15,000
Institute of Physics	10,000	10,000
Jesus College	5,000	5,000
CPS	1,000	2,000
Met Office	37,359	6,500
Director's Fund	40,000	40,000
U of Cambridge (Staff)	40,155	55,947
Rolls Royce	0	5,000
British Aerospace	0	5,000
British Airways	0	5,000
Thriplow Trust	0	6,000
Gonville and Caius	0	1,000
ConwayFest	0	300
EU Network Meeting	0	2,149
	1,487,560	1,382,437

The Research Councils (EPSRC and PPARC) provided 39% of total grant income (revenue plus workshop) during 1997/8.

Several grants have ended this year. These include funding from St John's College for rent (replaced by University of Cambridge funding); EC Leibniz funding (partially replaced by Marie Curie funding) and funding from the Information Services Committee towards computer maintenance.

In January 1997, the Isaac Newton Trust made a loan of £1M to the Institute, the interest to be used to meet overheads. As a result of the endowment of the NM Rothschild Professorship of Mathematical Sciences (the holder to be concurrently Director of the Newton Institute) the Trustees have agreed that this loan may now be converted to endowment. The level of interest from the loan in 1997/98 was high (£108,267) but this related to an 18-month period. It is expected anyway that the income will decrease in future years when some of the interest may be reinvested to maintain the value of the endowment.

Programmes attracted less additional funding in 1997/98 than in 1996/97. Nevertheless, key industrial sponsors supported the *Neural Networks and Machine Learning* programme and the Thriplow Trust gave a grant to the *Arithmetic Geometry* programme. The Meteorological Office again supported the *Mathematics of Atmosphere and*

Ocean Dynamics programme when a further short meeting on this topic took place. Other small amounts of funding were received which related to various special scientific events which took place at the Institute.

2. Computing Costs
It was decided to increase the computing budget for a number of reasons. For example, Silicon Graphics are providing several new machines for use by the Institute. These are renewed every six months. It is a condition that the Institute pays for a maintenance contract. In addition, other hardware maintenance costs have increased as have the costs of various software packages and licences.

3. Audio Visual, Capital Equipment, Equipment Repair and Maintenance
Figures for these items have decreased. 1996/97 was an exceptional year in terms of purchasing. Likewise, the cost of maintaining equipment decreased because the equipment concerned is new.

4. Building - Capital
These costs relate to the Library Gallery which was built in 1996/97. 'Snagging' was completed in 1997/98.

Financial Donations

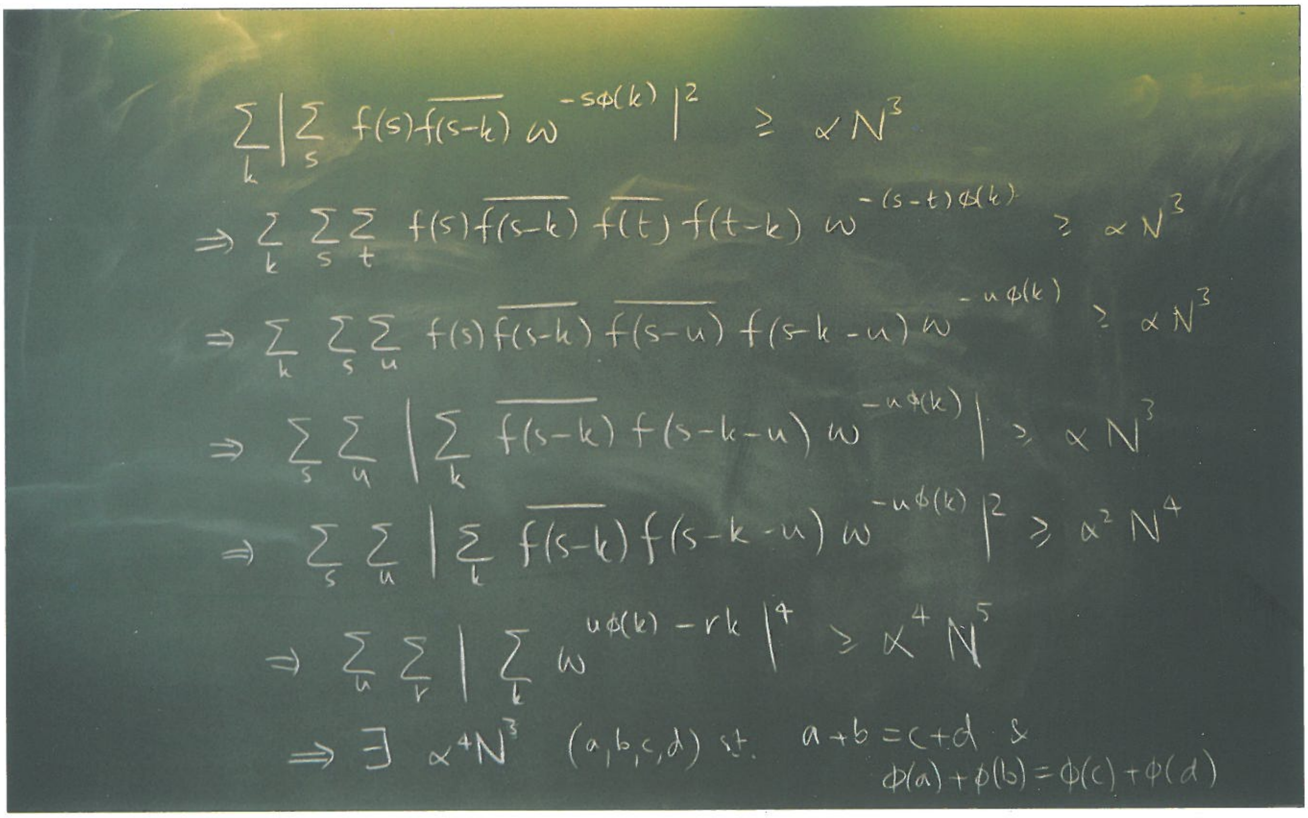
SERC/EPSRC	£5803k over 10 years
NM Rothschild and Sons	£2083k over 10 years
Isaac Newton Trust*	£2050k over 7 years
St John's College	£750k over 5 years
NATO	£529k over 7 years
Cambridge University	£512k over 9 years
Hewlett-Packard	£490k over 5 years
Le Centre National de la Recherche Scientifique	£435k over 10 years
European Union	£425k over 8 years
Leverhulme Trust	£375k over 6 years
Rosenbaum Foundation	£330k over 7 years
London Mathematical Society	£117k over 7 years
Gonville and Caius College	£100k
Prudential Corporation plc	£100k over 4 years
Institute of Physics	£68k over 7 years
Nuffield Foundation	£57k
British Met Office	£44k
AFCU (Hamish Maxwell) $50,000	£32k
AFCU (Anonymous Donation) $50,000	£32k
Emmanual College	£30k
Jesus College	£30k over 6 years
Daiwa Anglo-Japanese Foundation	£26k over 2 years
Corporate Members (FIN programme)	£22k
Thriplow Trust	£18k
Cambridge Philosophical Society	£15k over 10 years
Bank of England	£15k
Applied Probability Trust	£10k over 3 years
Trinity College	£10k
National Environment Research Council	£10k
Unilever	£10k
Schlumberger UK	£9k
Wellcome Trust	£7k
DSM (Netherlands)	£6k
GLOBEC	£6k
British Aerospace	£5k
British Airways	£5k
Christ's College	£5k
Harlequin Software	£5k
Rolls Royce	£5k
British Society of Rheology	£3k
Agricultural and Food Research Council	£2k

The Isaac Newton Trust donated £1,050,000 to the Institute over the first five years of its operation and has now given an endowment of £1,000,000.

Donations in Kind

Computer equipment has been donated by Hewlett-Packard, Sun Microsystems (who have also sold equipment to the Institute at a very substantial discount) and Apple UK. Silicon Graphics lends ten of its latest machines to the Institute. These are changed every six months. Software has been donated by NAG, Claris and Wolfram Research.

Over 4,000 books and journals have been donated by a large number of publishers and individual members of the mathematical community.



One day in the life of a Fields Medallist!

Front cover; An image from NASA/ESA's Hubble Space Telescope reveals clusters of infant stars that formed a ring around the core of barred-spiral galaxy NGC 4314. This stellar nursery, whose inhabitants were created within the past 5 million years, is the only place in the entire galaxy where new stars are being born.

Courtesy of G. F. Benedict, A. Howell, I. Jorgensen, D. Chapell (Univ. of Texas), J. Kenney (Yale Univ.), B. J. Smith (CASA, Univ. of Colorado), and NASA.

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