THE SECOND INTERNATIONAL REVIEW

International Perceptions *of* UK Research *in* Physics *and* Astronomy

2005

EPSRC
Engineering and Physical Sciences Research Council

PPARC
Particle Physics and Astronomy Research Council

Institute of Physics

Royal Astronomical Society
Advancing Astronomy and Geophysics

CONTENTS

FOREWORD

This Review is the ninth in a series aimed at providing international commentary on core fields of the UK's science and engineering research base, and is the second on physics and astronomy; the first was undertaken in 2000.

Since the publication of the 2000 review, *International Perceptions of UK Research in Physics and Astronomy*[1], the landscape of the UK's SET base has changed considerably, following the implementation of key government strategies for SET, including, "Investing in Innovation: A Strategy for Science, Engineering and Technology" (2002), and the "Science & innovation investment framework 2004-2014" (2004). The most significant development has been the increased investment into the UK's SET base, with a government commitment to increase the science budget to just under £3 billion by 2005-06 (more than double the figure in 1997-98), which includes increased funds for university infrastructure and salaries for PhD students and PDRAs. Some of the key changes are summarised in box 1.

Box 1: Key changes to the UK's SET base since 2000

- The launch of the £1 billion SRIF scheme (a third round was announced for the period 2006-08);
- An increase in the research council contribution to the indirect costs of research in universities, providing an extra £120 million a year over 2002-03 levels by 2005-06;
- An increase in the basic support for research council funded PhD students to an average of over £13,000 per year, and a funding increase in the average annual pay of research council PDRAs by £4,000 by 2005-06; with the increases in both cases being targeted in areas of recruitment and retention difficulties;
- EPSRC and PPARC are now providing support for PhD students for three and a half years on average and four years respectively;
- Grant proposals to the research councils will be made on a FEC basis from September 2005, with the research councils paying 80 per cent of research grants and fellowships. In addition, the government allocated an additional £120 million a year from 2005-06 and an additional £80 million a year from 2007-08 in order to make sure the current volume of research council supported research in universities is maintained on a sustainable basis;
- The creation of 1,000 new academic fellowship posts over five years;
- The establishment of a £0.8 million science resource centre to encourage female scientists to return to science and more women to pursue successful scientific careers;
- In July 2002 the "ticket" system for allocating facility access was closed. CCLRC took over the responsibility for allocating access to the facilities through facility access panels;
- The Diamond light source, a new synchrotron facility being built next to RAL, and a second target station is being constructed at the ISIS pulsed neutron spallation source at RAL.

[1] http://policy.iop.org/Policy/Intrev.html

In addition, the 2000 international panel made a number of recommendations to improve the UK's physics and astronomy research efforts, which were implemented by the research councils. Some of the key changes are summarised in box 2.

Box 2: Key changes to the physics and astronomy research base since 2000

- The UK, through PPARC, became a formal member of ESO in July 2002;
- EPSRC allocated £10 million for an IRC in Quantum Information Processing;
- A six year EPSRC grant was awarded in 2000 (£11 million) for an IRC in Ultrafast Photonics for Datacomms above Terabit Speeds comprising six leading universities and five industrial collaborators;
- The EPSRC Physics and Life Sciences Interface Programmes began a series of calls for feasibility studies starting in 2004 to encourage collaboration between these two fields. £1.4 million was allocated in the first call funding 16 proposals;
- The area of particle astrophysics has been considerably strengthened by PPARC approval for UK involvement in Advanced LIGO and CLOVER as well as continued support for involvement in the Pierre Auger Observatory, Veritas, HESS and Dark Matter searches.

Following the changes to the funding landscape for research in the UK since the 2000 review, it is timely for this Second International Review of UK physics and astronomy research to benchmark its standing in comparison to other leading scientific nations, and to provide the Engineering and Physical Sciences Research Council (EPSRC) and the Particle Physics and Astronomy Research Council (PPARC) with a better understanding of the strategic position of the subject, as perceived by a panel of international scientists.

The Review also coincided with the centenary anniversary of the publication of Albert Einstein's seminal scientific papers on Brownian motion, the photoelectric effect, and special relativity. The impact of his work on our current science and technology is incalculable and the anniversary underlines the importance of curiosity-driven research of the highest quality to our understanding of the world and as a platform for advances in technology.

The Review was initiated under the sponsorship of EPSRC, PPARC, the Institute of Physics and the Royal Astronomical Society. The Institute of Physics and the Royal Astronomical Society, as representatives of the scientific research community, were involved to facilitate engagement with their respective communities.

The Review was overseen by a Steering Group comprising:

Professor Sir John Enderby FRS (Chair), President, the Institute of Physics
Professor John O'Reilly FREng, Chief Executive, EPSRC
Professor Ian Halliday FRSE (until March 2005), Professor Richard Wade (March-August 2005), and Professor Keith Mason (August 2005-present), Chief Executives, PPARC
Professor Kathryn Whaler, President, the Royal Astronomical Society

The Institute of Physics provided the Secretariat for the Steering Group and the Panel: Professor Peter Main, Philip Diamond, Tajinder Panesor and Vanessa Crichton. Support was also provided by Jane Nicholson and Dr Joanna Coleman (both EPSRC), Dr Catherine Ewart and Nigel Calvin (both PPARC), and Dr Mike Hapgood (the Royal Astronomical Society).

The Steering Group, in collaboration with the Chair of the Panel, advised upon the range of materials to be prepared for the Panel. These materials are described in appendix A.

The Panel, from left to right:

BACK ROW: Richard Casten, Hermann Gaub, Anton Zeilinger, Stephen Forrest, Tuija Pulkkinen, Albrecht Wagner, Sir Anthony Leggett FRS, Daan Frenkel and Massimo Inguscio.

FRONT ROW: Roger Blandford FRS, David Gross, Mildred Dresselhaus, Jürgen Mlynek (Chair) and Govind Swarup FRS.

The membership of the Panel was determined by the Steering Group, following a call for nominations from the UK's academic physics and astronomy community. The principal criterion shaping the composition of the Panel was that the sub-fields of physics and astronomy should be covered as fully as possible. In addition, it was decided that the Chair, and a number of other panel members, should be selected from the 2000 international panel, in order to ensure continuity. Information on the Panel can be found in appendix D.

The Steering Group is extremely grateful to the Panel, particularly the Chair, Professor Jürgen Mlynek, for the time committed to the Review, and the conscientious and thorough approach taken to the work. The report will be important to all the sponsors, especially EPSRC and PPARC, in helping to shape their future strategies for the support of physics and astronomy research in the UK. The report is commended to the UK's academic physics and astronomy community for its consideration and comment.

Professor Sir John Enderby FRS, President, the Institute of Physics

Professor John O'Reilly FREng, Chief Executive, EPSRC

Professor Keith Mason, Chief Executive, PPARC

Professor Kathryn Whaler, President, the Royal Astronomical Society

EXECUTIVE SUMMARY

The Second International Review of UK physics and astronomy research coincided with the centenary anniversary of the publication of Albert Einstein's seminal scientific papers. The last century has witnessed an enormous return on basic physics research investments – much of the increase in wealth, economic globalisation, living standards and the quality of life in the 20th century has been based on technological progress, which in turn has relied heavily on innovative research in physics and astronomy. These trends are anticipated to continue and, indeed, strengthen in the 21st century. The case for the UK, as a leading economy, to continue to support physics and astronomy research on a broad basis remains overwhelming. Furthermore, as society becomes increasingly technological, understanding basic physical concepts has become an increasingly important and integral part of our culture.

GENERAL OBSERVATIONS

The Panel was delighted to note that considerable efforts have been made to improve the status of physics and astronomy in the UK, in particular to address the structural issues that the 2000 report highlighted. This comment is especially pertinent to the investment for infrastructure through the JIF and SRIF initiatives, and the significant increase in the funding of all aspects of physics and astronomy since 2000. The Panel also noted the additional investment in human resources, such as the much-needed adjustment of stipends for PhD students to an acceptable level.

In addition, the Panel was struck by the general improvement in the research environment and the positive outlook of those involved with the research effort at all levels. Progress has clearly been made and the UK is now well placed to reap the benefit of the investment that has been made since the 2000 review. This progress, however, is predicated on maintaining the increased level of funding that has taken place over the last few years. The Panel cannot overstress the importance of this funding for the continued health of the subject, and for continuation of the benefits it brings to society and the economy.

FINDINGS ON THE SUB-FIELDS OF PHYSICS AND ASTRONOMY

ASTROPHYSICS AND SOLAR SYSTEM PHYSICS

- The UK continues to enjoy a high standing in astrophysics and solar system physics. The best departments and individuals have outstanding international reputations and there has been considerable growth on several fronts since the 2000 review, both in terms of participation in large international projects and in developing new research areas. The astrophysics and solar system physics enterprise is poised for a very productive decade.

- The Panel is pleased to note that the UK funding agencies have recognised the specific needs of the long-term space and ground-based projects that often last more than a decade from instrument design to data analysis. However, it is imperative to ensure that the funding agencies maintain a healthy balance between the large investments in international facilities and funds spent nationally for exploitation of these opportunities through experiment development and data analysis programmes. This applies especially to the astronomical observing communities, which need building up so as to recoup the investment in access to Gemini, VLT and ALMA. The relatively few opportunities for solar system physics and astrophysics missions within ESA require careful planning, both from the solar system physics and astrophysics communities and the funding agencies. Finally, a response will be needed to an increased demand for computational facilities that will arise from both data analysis and simulation needs.

ATOMIC, MOLECULAR AND OPTICAL PHYSICS

- Since the 2000 review, the UK atomic and molecular physics community has responded to the challenges that were highlighted, including efforts to achieve critical mass in the field of cold atoms. However, the UK has still not (fully) recovered its leadership position in the field of atomic physics. In order to do so, the UK should continue to develop cold atom physics research and to recruit young researchers into the field. There are promising areas to investigate, many of which are at the interface with other research fields.

- Quantum information and quantum computation has continued to experience vigorous growth worldwide. UK theorists have always played a leading role but, with a few notable exceptions, that pre-eminence does not seem to be matched on the experimental side. While the QIPIRC initiative provides broad support to many teams, the support of individual groups appears to be below the critical level. The Panel recommends that the UK makes better use of its standing in theory by providing more adequate funding for experimental groups, with the aim of encouraging a closer interaction between the two.

- UK research continues to be internationally innovative in the fields of laser physics, nonlinear optics and photonics. Very influential projects include ultrafast lasers and in-fibre lasers, as well as the development of new nonlinear materials with control over the refractive index. Support of the field should be continued, particularly in view of its potential, both in opening new avenues for fundamental research and also developing optical communication technology and ultimate frequency metrology.

CONDENSED MATTER PHYSICS

- Historically, condensed matter physics in the UK has had very high peaks of excellence, and the recent injection of funds to enhance the infrastructure base has had a noticeable effect on improving the mean quality of research throughout this diverse field of physics. It is the opinion of the Panel that fundamental condensed matter physics has some notable strengths, although some important fields of research still fall below a standard of international leadership.

- One particular area still requiring attention is nanoscience. This area of research has become a very large area of emphasis worldwide, yet the UK lacks coherence and international visibility in the field. Another broad area of research that is still suffering from patchy coverage is surface science. Expertise in this area is of central importance to advances in nanoscience.

NUCLEAR PHYSICS

- The Panel felt that UK nuclear physics research is first class, has high international prominence, and has improved since the 2000 review. This work is both experimental and theoretical, and emphasises low energy nuclear structure and nuclear astrophysics but with significant efforts to study hadron structure and to characterise the quark gluon plasma. In terms of balance, the UK nuclear physics effort, by funding necessity, is more niche-oriented than all encompassing, but the niches are well chosen, and the principal one, exotic nuclei, is the next frontier area in the field, which positions the UK to prosper in the long term.

- Nuclear theory in the UK is a small but first class effort, with high international visibility, focusing largely but not exclusively on light exotic nuclei and the nuclear reactions involving them. The fact that this effort is small in absolute terms means that it is essential that it be nourished and sustained, lest it fall below critical mass.

PARTICLE PHYSICS

- UK research in the field of particle physics is of a high quality and internationally very visible. UK particle physics has, for many years, made effective use of frontline accelerators worldwide. Researchers from around 25 universities are performing a broad experimental programme and are involved in most major experiments around the world. Research is focused on the central questions of the field, both through involvement in current experiments and through a strong engagement in the high-potential experiments of the coming years and decades. UK physicists carry the responsibility for key detector components and often hold leadership positions.

- Particle theory in the UK is healthy, with a revitalised effort in particle phenomenology, a burgeoning contribution to the physics that might lie beyond the Standard Model, a strong and vital group of lattice theorists and continuing strength in string theory and general relativity. The strengthening of particle physics over the past five years will ensure a continuation of the leadership role and high visibility of the UK.

SOFT MATTER AND BIOPHYSICS

- Experimental and theoretical soft matter physics emerged as a vibrant area of research in the UK at a time when, internationally, the field was still quite small. At present, the UK has a small number of groups that are internationally prominent in the experimental, theoretical and computational study of colloids, polymers and surfactants. However, it is the perception of the Panel that there are quite a few physics departments where students get little, if any, exposure to modern soft matter physics. This is regrettable, because soft matter physics has deep links with many other areas of science, whilst the theoretical concepts and experimental techniques of this field are of direct relevance for biophysics. In addition, soft matter physics has many industrial applications.

- Biophysics, which went through a phase of reorientation in the UK in the mid-1990s, has been rejuvenated during the last five years, particularly with new initiatives in the fields of single-molecule biophysics, molecular motors and nanobiotechnology. However, the Panel observed that the majority of the internationally visible biophysics research is not conducted in physics departments. The drain of physicists active in interdisciplinary research out of physics departments, will limit the exposure of UK physics students to one of the fastest growing areas in modern physics reaching out into other scientific fields.

GENERAL FINDINGS ON PHYSICS AND ASTRONOMY

HUMAN POTENTIAL

- The Panel is of the view that physics has a unique place in a knowledge-based society, as a discipline that underpins the other core sciences and engineering.

The Panel is deeply concerned that physics has ceased to be an identifiable discipline in a number of UK universities. A continuation of this trend would threaten the UK's ability to produce the volume of physics graduates needed for it to compete on an international basis. The Panel is disturbed to find that the financial health of university departments is to a significant degree dependent on undergraduate numbers, which themselves depend on career choices of young people in the secondary system. This is not a good basis for strategic planning of the science base.

- The Panel understands that the short duration of UK PhD training compared to other leading scientific nations has some advantages, for example the efficient flow of people into the employment market at an earlier age. However, this is undermining the ability of UK PhD graduates to compete with their international counterparts for postdoctoral fellowships, both at home and abroad. The Panel is of the view that the UK needs to make an informed decision about the future of its graduate training programme. In order to do this, it should commission an in-depth review of graduate level education, which needs to incorporate comparisons with its leading scientific competitors.

- The situation of the perennial PDRA, going from one short-term contract to another, with the associated uncertainty, is not the ideal environment in which to nurture young academic talent. The situation has not improved since the 2000 review, and it is imperative that advice on long-term career prospects is provided to PDRAs at an earlier stage.

- The Panel is still concerned with the low number of female faculty in university physics and astronomy departments. Even though the situation has greatly improved since 2000, the Panel is of the opinion that it should be the aspiration of each department to have at least two female academic members of staff on its faculty by the end of the decade. To achieve this goal, special focus to attract (and subsequently to retain) women into science is needed from the very early stages onward.

- Since the 2000 review, the Panel has noticed an increased internationalisation of the people involved in physics and astronomy research at all levels. The Panel believes that this is a positive development, which reflects the increased competition for the very best people independent of nationality. However, this does not appear to be the case for non-EU nationals at the graduate level. The Panel wonders whether there are funding barriers to recruiting non-EU students and, if so, would urge the appropriate agencies to review the regulations.

THEORY

- The Panel is concerned with the number of theorists in UK physics and astronomy departments, which it believes is below the international norm. The benefits from the recent investment in infrastructure and funding for research have not led to a substantial increase in theoretical physics activity. A noticeable exception is the strong revival of particle physics phenomenology with the founding of the IPPP at the University of Durham. Similar efforts should be contemplated to reverse the noticeable decline in world-class leadership in some other sub-fields of physics.

FACILITIES

- The central laboratories at RAL and Daresbury play a crucial role in enabling projects that are too large for universities. The Panel was pleased to observe that money has been invested to sustain world-class facilities, such as ISIS, which is undergoing a major expansion, and the construction of the Diamond synchrotron light source. The Panel heard, however, that there had been a reduction in the number of graduate students associated with the use of central facilities, which is unfortunate as they provide a unique training opportunity.

- Large research facilities in physics, astronomy, and space science are increasingly organised, funded and operated at an international or world level. The UK has been a long-standing member of several European facilities and has recently joined ESO. The Panel is pleased that the UK plans to continue this development through possible involvements in European projects, for example in nuclear physics (e.g. the FAIR project at GSI) and in an X-ray Free Electron Laser, and, on a longer timescale, through an active role in the International Linear Collider. These investments should be carefully balanced with national funding targeted at the exploitation of the opportunities provided by these facilities.

RESEARCH COUNCIL FUNDING

- Curiosity-driven research is important in its own right and attracts the most able people into physics and astronomy, but it is also the foundation for the improvement of quality of life and wealth creation in a knowledge-based society. The Panel has noted that some new money entering the science base has been tied up with specific initiatives. Many of these initiatives may be of strategic importance to the UK. However, the Panel is concerned that this could be a creeping trend that would undermine the opportunities of physicists and astronomers to follow their instincts in research, and the UK's ability to pursue curiosity-driven research at the highest level. The Panel recommends that the research councils monitor the balance between targeted and curiosity-driven research and maintain a healthy balance between the two funding streams.

- Innovative basic research requires a long planning horizon, often exceeding a three- to four-year period. The Panel observed that this appears to be the normal funding period for grants within EPSRC (only a small proportion of PPARC grant funding is provided through short fixed-term grants) and that it is sometimes difficult to obtain continuation funding. The Panel urges EPSRC to establish mechanisms to support the most innovative and challenging research for longer time periods. Without such support, it will be difficult for the very best to remain competitive with their counterparts from other leading scientific nations.

- The Panel encourages the research councils to implement mechanisms to stimulate more interdisciplinary research; this is a particular concern at the interface between physics and the life sciences, which is a fertile area at present. The Panel does not believe that the managed programme mechanism is the right way of supporting this research, and that flexibility must be created within the research council's existing responsive mode funding route to recognise and accommodate high-quality interdisciplinary research proposals.

FULL ECONOMIC COSTS

- The Panel gives a cautious welcome to the introduction of FEC while having some concern over a potential diminution in the volume of research the UK conducts. The Panel trusts that the impact of FEC will be monitored closely and recommends that contingency funds be in place if it becomes evident that support for research is being undermined.

1. INTRODUCTION

1.1 TERMS OF REFERENCE

The Panel was asked:

- to report on the quality, distribution of effort and future potential of research in physics and astronomy in the UK;
- to indicate areas of strength, weakness, improvement, decline and growth with respect to the 2000 review;
- to compare with and contrast to the very best research internationally in equivalent research areas; and
- to provide recommendations that point out aspects that need special attention either to strengthen, halt decline or ensure a capacity to respond to future opportunities.

The Panel declined to offer comment on the research efforts in plasma physics and medical physics, as it felt it did not have sufficient expertise in these areas.

1.2 INPUT DATA

The Panel was able to draw upon the following sets of input data (see appendix A):

1.2.1 Experience and knowledge of UK research and of the British physics and astronomy community by the panel members in their areas of expertise.

1.2.2 A '*Background and Information Data Document*', which is a substantial body of data on the funding, staffing and outputs of physics and astronomy research throughout the university and research council sector, collected and collated by the Secretariat.

1.2.3 A '*Key Issues Paper*', which used the 2000 report as a baseline, to highlight the key changes that have taken place in the science base, and the individual sub-fields of physics and astronomy on which the 2000 international panel commented, and suggested recommendations for support and improvement.

1.2.4 The results of a questionnaire sent out by the Panel to their non-UK colleagues, with the aim of providing the Panel with a broad-based view of the quality of UK physics and astronomy research being undertaken in their particular sub-fields.

1.2.5 The programme of site visits for the Panel was devised by the Steering Group and agreed by the Chair of the Panel. The Panel was divided into four sub-groups reflecting their research expertise. Departments at the following universities were visited[2]:

University of Cambridge
Cardiff University (plus University of Wales Swansea)
University of Durham
Lancaster University
University of Leicester
University of Liverpool
Liverpool John Moores University
Imperial College London
University College London
Scottish Universities Physics Alliance (at University of Glasgow)
University of Warwick

The Panel also visited the CCLRC Rutherford Appleton Laboratory.

All the university departments were requested to complete a comprehensive data template, in order to provide the Panel with a comparable set of information and statistics on their research as well as providing an insight into their research priorities. The visits to the university departments consisted of presentations and informal discussions with academics, PDRAs and PhD students. These discussions provided invaluable insights to the research environment in the UK.

1.3 CAVEAT

In the time allotted to this Review, it was impossible for the Panel to obtain a comprehensive understanding of all the issues, problems and ramifications concerning physics and astronomy research in the UK. Therefore, this report is a concise summary of perceptions that the Panel shared based on their prior experience, comments from their non-UK colleagues, material provided by the Secretariat, and the university department site visits that took place during the Review week.

[2] Individual panel members also visited groups at University of Oxford

The Panel felt that the dozen or so university physics and astronomy departments and the one central facility were the very minimum for such a programme of visits. Despite these limitations, there was a general consistency in the impressions the Panel obtained regarding the stature of physics and astronomy in the UK and of the problems and opportunities that present themselves.

The Panel doubts, however, whether a more thorough evaluation would have led to substantially different conclusions than those presented in this report. Despite any shortcomings, the Panel believes that its report has the particular strength of international perspective and independence and that it will find a useful place in the range of inputs that shape UK research policy in physics and astronomy, and in relevant interdisciplinary research.

1.4 ACKNOWLEDGEMENTS

The Panel wishes to thank the Steering Group, and in particular, the Secretariat for their excellent scientific and logistical support; without their enthusiasm, co-operation and thoughtfulness, the whole exercise would not have been possible. Furthermore, the Panel would like to express its gratitude to the physics and astronomy university departments and the CCLRC Rutherford Appleton Laboratory who received the Panel for the visits.

2. FINDINGS ON THE SUB-FIELDS OF PHYSICS AND ASTRONOMY

2.1 ASTROPHYSICS AND SOLAR SYSTEM PHYSICS

The UK continues to enjoy a high standing in astrophysics and solar system physics. The best departments and individuals have outstanding international reputations and there has been considerable growth on several fronts since the 2000 review, both in terms of participation in large international projects and in developing new research areas. The astrophysics and solar system physics enterprise is poised for a very productive decade.

In astrophysics, the traditional emphasis on cosmology, extragalactic astronomy and high energy astrophysics has continued. UK scientists have participated centrally in major advances in observational cosmology, defining the Standard Model and measuring the average density of dark matter and galaxy formation and evolution, understanding how neutron stars and black holes form and behave in stellar systems, including gamma ray bursts, and the nuclei of active galaxies and gravitation. In the other general area where there have been great discoveries, the study of extrasolar planets and star formation, UK scientists are now more prominently represented. Theoretical groups continue to lead the way in fundamental research, phenomenology and in defining new observational facilities, particularly in the fields of microwave background research, pulsars and X-ray astronomy. Instrumentation is also flourishing, especially in radio, terahertz and X-ray astronomy, and the technology development appears to be well matched to many of the prime observational ambitions. Observationally, the UK has enjoyed access to new facilities, in particular after it became a full member of ESO, as was recommended in the 2000 review. The Gemini and VLT telescopes are being used to produce important observational results, in particular involving stellar kinematics, the intergalactic medium, high redshift galaxies and transiting planets. In radio astronomy, MERLIN should enjoy a further decade as a unique instrument and JCMT should be rejuvenated following the installation of SCUBA-2.

The situation is similar in many areas of solar system physics. UK researchers have an exceptionally strong standing in solar physics as well as space-based and ground-based space physics. The UK has a world-leading role in helioseismology, dynamo theory, coronal activity, magnetic reconnection, and shock physics, thus covering many of the important aspects of the Sun-Earth connection. However, the UK contributions to planetary science do not cover all sub-fields as evenly, and tend to focus on the plasma environments of the planetary bodies: strong sub-fields include, for example, planetary magnetospheres, atmospheres and exobiology, while planetary geology and interiors studies lag behind those in France, Italy and the US. UK investigators are active in operating missions including Cluster, the Solar and Heliospheric Observatory, Mars Express and Cassini-Huygens at Saturn and Titan.

The opportunities for the UK astrophysics community over the next decade are considerable. Herschel and Planck will be launched in 2007 and will lead to major advances in far infrared astronomy and the study of microwave background fluctuations respectively. The infrared survey telescope, VISTA, should be operational in 2007. The UK is making a large investment in the major European-North American-Japanese millimetre interferometer, ALMA, which is likely to be a premier observatory for 40 years. Investment in ALMA research support should be commensurate with the capital investment and research opportunity. Gravitational radiation detectors are now collecting science data and may open a brand new window on the universe. On a longer timescale, UK radio astronomers have been very active in planning the Square Kilometre Array, which represents the future of radio astronomy, whichever of several competing designs is eventually chosen. Even more ambitious is the ESO-led Extremely Large (optical) Telescope, expected to be between 30 to 60 metres in diameter. This proposal has tremendous potential for all fields of astronomy. However, the development presents considerable technical and engineering challenges. Investment in this project should be paced by technical progress and fiscal realism.

The UK is actively pursuing the next-generation space instrumentation and will collaborate on the Japanese-led Solar-B, NASA's Solar Dynamic Observatory and STEREO missions, and is actively taking part in planning ESA's next near-Earth space physics mission. The UK has a world-leading role in ground-based space research using ionospheric radars, auroral observations, and magnetometer networks, which today is best visible in its leadership role in the international working group combining the ground-based observations together with the data from ESA's Cluster satellites. The ground-based space research is highly cost-effective relative to space-based science, and increased support would likely yield great dividends as well as valuable hands-on experience for PhD students and PDRAs.

The UK's funding agencies have recognised the special needs of the long-term space and ground-based projects, which often last more than a decade from instrument design to data analysis. However, it is important to take care that the funding agencies have sufficient means to maintain a healthy balance between the large investments in international facilities and funds spent nationally to exploit these opportunities through experiment development and data analysis programmes. There are recent examples where the money invested in ESA programmes has not been fully capitalised because it has not always been possible to support an instrument programme commensurate with the UK subscription. In a world of limited funds, it may be necessary to seek a balance between major contributions on fewer projects and minor participation in a large number of missions.

There have been significant UK-led advances in computational astrophysics and data analysis, especially applied to cosmology and astrophysical fluid dynamics, including helioseismology. There are growing fields and there will likely be demands for greater computing capability in several areas. First and foremost, the coming generation of telescopes will produce petabyte databases and corresponding analysis challenges. Theoretically, in addition to the demands of existing sub-fields there is likely to be relative growth in solar system computational physics and gravitational radiation calculations.

UK astronomers and space scientists have been at the forefront of efforts to improve the public perception of physical science through the many communicable and interesting discoveries in their field. In particular, they seem to have been very effective in reaching academically promising schoolchildren and explaining the diverse benefits and opportunities that derive from a physics or engineering education. The ill-fated Beagle-II Mars Lander tapped an unprecedented public interest in planetary science, while teaching some important lessons in the management of space missions. Furthermore, the UK research community has had a leadership role in developing the European space weather programme, which has both increased space science visibility as well as providing new applied results for the entire space user community.

In summary, the state of astrophysics and solar system physics is relatively healthy at this time. Morale is good in the research community, particularly among the young, and wise investments seem to have been made since the 2000 review. Attention will need to be paid over the next five years to foster the astronomical observing community so as to recoup the investment in large telescope access. The significant investments to ALMA call for special programmes designed to support millimetre astrophysics. The relatively few opportunities for space physics missions within ESA require careful planning, both from the space physics community and the funding agencies. Finally, a response will be needed to an increased demand for computational facilities that will arise from both data handling and numerical astro- and space physics needs. From the human potential point of view, it is necessary to plan stable career paths for young people working in long-term research projects, as well as to guarantee that the UK research groups receive the recognition their work in international collaborations deserves.

2.2 ATOMIC, MOLECULAR AND OPTICAL PHYSICS

Since the 2000 review, the UK atomic and molecular physics community has responded to the challenges that were highlighted. A small amount of support has been given to a UK Cold Atom Network by EPSRC and this has been useful to encourage efforts to achieve critical mass and to develop a co-ordinated strategy for the field. Cold atomic species are now widely investigated and Bose-Einstein condensates have been obtained in several laboratories as a result of dedicated financial support.

However, the UK has still not (fully) recovered its leadership position in the field of atomic physics. In order to do so, the UK should continue to develop cold atom physics research and to recruit young researchers into the field. There are promising areas to investigate, many of which are at the interface with other research fields. For example, atom chips linking cold atoms with microfabrication; cold molecules and cold collisions, linking physics with chemistry; or the development of cold-atom-based condensed matter physics with the possibility of a precise control of quantum interactions, in collaboration with many-body theorists. Other important fields relate to the investigation of fundamental laws of physics with tabletop experiments, such as the investigation of the electric dipole moment. UK research groups are individually participating with European research networks, although the activity in the field could certainly benefit from the UK entering into formal partnerships with Austria, France, Germany or Italy, countries that have a record of innovation in this field.

The field of quantum information and quantum computation has continued to experience vigorous growth worldwide. UK theorists have always played a leading role, not only creating some of the seminal ideas and concepts but also successfully continuing to command a world-leading position. With a few notable exceptions, that pre-eminence does not seem to be matched on the experimental side. While the QIPIRC initiative provides broad support to many teams, the support of individual groups appears to be below the critical level. The very few leading groups have had to supplement their UK funding with significant non-UK support in order to maintain their standing. The Panel recommends that the UK makes better use of its standing in theory by providing more adequate funding for experimental groups, with the aim of encouraging a closer interaction between the two. This is particularly important in view of the immense global effort in these areas, which is based on the expectation that promising new technologies will emerge with a concomitant economic return.

UK research continues to be internationally innovative in the fields of laser physics, nonlinear optics and photonics. Very influential projects include ultrafast lasers and in-fibre lasers, as well as the development of new nonlinear materials with control over the refractive index. Support of the field should be continued, particularly in view of its potential, both in opening new avenues for fundamental research and also developing optical communication technology and ultimate frequency metrology.

The entire field of atomic, molecular and optical physics would benefit greatly from a strategic interaction with the National Physical Laboratory, analogous to the arrangements in other countries, for example France and Germany.

2.3 CONDENSED MATTER PHYSICS

Historically, condensed matter physics in the UK has had very high peaks of excellence, and the recent injection of funds to enhance the infrastructure base has had a noticeable effect on improving the mean quality of research throughout this diverse field of physics. It is the opinion of the Panel that fundamental condensed matter physics has some notable strengths, although some important fields of research still fall below a standard of international leadership. However, applied research in materials and electronic devices has truly distinguished itself in the UK physics community by achieving international visibility in a number of areas.

One particular area of strength that continues to grow in international influence is the area of polymeric materials and polymer electronics. This important and growing area of research is broad based, with several groups across Britain having an unquestioned world leadership. Their research strengths extend from synthesis and morphological control of film microstructure, to fundamental research in charge transport, and ending at application to devices. Exciting results in areas of polymeric exciton physics, while currently at a fundamental level, may one day result in a new generation of devices and device physics. While the experimental aspects of polymer electronic materials are extensively covered, theoretical studies that accompany the advances are somewhat less well developed.

In photonic materials and devices based on compound semiconductors such as gallium arsenide, indium phosphide and silicon-germanium, the UK has taken a highly visible and, in some instances, a leadership position worldwide. On the fundamental side, work in some aspects of nonlinear fibre optics and photonic band gap structures is clearly world-class, although a preponderance of the advances in photonic materials and devices tends to be more applied than other subjects covered in condensed matter physics due to its obvious commercial potential. Nevertheless, basic materials research, particularly relating to quantum-confined structures, has some notable strengths. There are also some examples where photonics research based on combinations of organic and inorganic semiconductor materials has started to emerge. The Panel finds this to be a promising area of cross-disciplinary research that should continue to be encouraged.

The Panel notes that research in both polymers and photonic materials has been aggressively and successfully coupled to applications by spawning new industries within the UK, particularly in the south of England and along the Scottish “photonics corridor” extending from Glasgow to Edinburgh. This collective activity is breaking new ground in forging strong industry-academic ties – a welcome development that the Panel hopes will continue to grow and spread into other areas of physics, producing many obvious opportunities for improving the economic well being of society in general. Perhaps even more importantly, however, this linkage provides arguably the best means for communicating to the British public the value of pursuing fundamental science.

Another area where the UK has distinguished itself is in experimental low temperature physics. Indeed, recent work on superconductivity and on magnetism has attracted considerable international attention, and the UK effort in ultralow temperature physics has maintained its international leadership position.

One particular area still requiring attention is nanoscience. This area of research has become a very large area of emphasis worldwide, yet the UK lacks coherence and international visibility in the field. The Panel believes that excellence in this interdisciplinary area is essential for the UK to maintain a significant international presence in condensed matter physics as a whole. The Panel notes considerable investment has been made in providing state-of-the-art infrastructure for the purpose of investigating the properties of materials at the nanoscale. It is anticipated that, in the next few years, these new resources will create a climate whereby an internationally recognised effort in the field will emerge in the UK.

Another broad area of research that is still suffering from patchy coverage is surface science. This field typically concentrates on the mechanisms for thin film and quantum structure growth, and often reveals the energetic relationships between heterogeneous materials at their interface. In that way, it provides “glue” between theory and experiment, and between 3-D and confined lower dimensional systems. Expertise in this area is, therefore, of central importance to advances in nanoscience. The Panel believes that, while some notable work is occurring in surface science in the UK, the country as a whole does not have the expected international leadership in this important area. Nevertheless, there are world-class facilities at RAL for revealing the morphological and energetic properties of thin films that are accessed by the international physics community for this purpose. The UK is therefore well placed to move into an internationally recognised leadership position in surface science, provided that interest in this field can be sufficiently nurtured.

Finally, the UK has maintained considerable strength in theoretical research in the soft condensed matter area, despite the apparent decline in the number of practitioners, at least those based in physics departments. If this trend continues, however, the quality of research will eventually suffer. Nevertheless, there has been a substantial contribution in the area of ab-initio electronic structure calculations, and some related areas of traditional solid-state physics. However, the contribution of the UK is less prominent in the complex of problems which is often regarded as the core and most challenging area of condensed matter theory, such as the co-operative behaviour of strongly correlated electrons as manifested in, for example, the cuprate superconductors, the fractional quantum Hall effect, and the behaviour of complex magnetic oxides. Despite a few notable exceptions, the Panel believes that, overall, the UK condensed matter physics community would be better served by stronger interactions between theory and experimental efforts; it was the Panel's impression that there is often too little contact between such groups, even though they may be working at the same institution on closely related areas.

2.4 NUCLEAR PHYSICS

The Panel felt that UK nuclear physics research is first class, has high international prominence, and has improved since the 2000 review. This work is both experimental and theoretical, and emphasises low energy nuclear structure and nuclear astrophysics but with significant efforts to study hadron structure and to characterise the quark gluon plasma. In terms of balance, the UK nuclear physics effort, by funding necessity, is more niche-oriented than all encompassing, but the niches are well-chosen, and the principal one, exotic nuclei, is the next frontier area in the field, which positions the UK to prosper in the long term.

With the closure of the Daresbury Tandem facility, the low energy nuclear physics groups in the UK adopted a strategy of pooling their talents to pursue involvement in offshore facilities. They adopted a proactive role, focusing on the design and construction of state-of-the-art-defining instrumentation.

This strategy paid off – these groups are embedded in essential and productive ways at leading centres for nuclear structure research, carrying out world-class experiments and often driving new initiatives. The main focal points of UK effort abroad are GANIL/SPIRAL in France, GSI in Germany, CERN-ISOLDE in Switzerland, Jyvaskyla in Finland, Argonne National Laboratory and Berkeley in the US, and TRIUMF in Canada. UK contributions to the development of instruments such as EXOGAM, VAMOS, TIARA, RISING, GREAT, SACRED, JUROGAM, TUDA and TIGRESS are essential to their success. Looking to the future, the UK is playing a major developmental role in AGATA, a high efficiency gamma ray tracking array, in studies of exotic nuclei at the future FAIR project at GSI through the UK-led NUSTAR collaboration, and in design work for EURISOL. The potential for this research is outstanding.

Exotic nuclei provide the best route to pursue the twin challenges of understanding how to build up complex nuclear many-body systems from simple ingredients while, conversely, understanding the astonishing simplicities, regularities, and symmetries that they display. The long-term goal is to develop a comprehensive, unified nuclear theory, applicable to all nuclei. (Traditional models are likely to be projections of an (unknown) general theory onto the subset of nuclei near stability that spawned these models.) Access to exotic, highly proton-neutron asymmetric, nuclei offers new opportunities to pursue this quest. Weakly bound nuclei near the drip lines exhibit entirely new phenomena such as exotic topologies (e.g. halos and skins) and collective modes, density variations that alter in-medium, nucleonic interactions, changes in both mean field and residual interactions, and altered shell structure.

Technological advances that provide access to broad ranges of exotic nuclei offer a greatly expanded gene pool of nuclei in order to choose those that isolate and amplify particular physics, and to study structural evolution and phase transitional behaviour across long iso-chains. The study of exotic nuclei is also essential for nuclear astrophysics, since most of the energy-producing processes in stellar environments, and most nucleosynthesis, involves reactions of unstable nuclei.

UK nuclear physicists are making outstanding contributions on a number of these topics. World-class work is taking place on N=Z nuclei, where the T=0 interaction produces structural singularities, on the fragility of magicity in shell structure, halo nuclei, the surprising stability of superheavy nuclei against centrifugal disruption, nuclear masses and radii, isomer spectroscopy, and proton emitters. This is complemented by studies of neutron-rich nuclei with deep inelastic reactions and fission fragments. In nuclear astrophysics, forefront work is pursued on breakout from the CNO cycle, the rp-process, and explosive nucleosynthesis. The UK also mounts a high quality effort in hadron structure and the origin of nucleon spin, carried out at JLab, MAMI, and DESY, and relativistic heavy ion studies at RHIC.

Nuclear theory in the UK is a small but first class effort, with high international visibility, focussing largely but not exclusively on light exotic nuclei and the nuclear reactions involving them. The fact that this effort is small in absolute terms means that it is essential that it be nourished and sustained, lest it fall below critical mass.

There are concerns for the future. The first is the need for stable long-term funding profiles befitting the kinds of extended research and instrumentation projects the UK community is involved in. The second relates to the status of UK participation in major offshore nuclear facilities (e.g. the FAIR project at GSI). Membership along the lines of existing memberships in CERN or ILL confers a status and influence that small groups cannot attain. Having opted to forego onshore facilities, it is now incumbent on the UK to provide the means to pursue forefront research elsewhere.

2.5 PARTICLE PHYSICS

2.5.1 EXPERIMENT

UK research in the field of particle physics is of a high quality and internationally very visible. UK particle physics has, for many years, made effective use of frontline accelerators worldwide. Researchers from around 25 universities are performing a broad experimental programme and are involved in most major experiments around the world. Research is focused on the central questions of the field, both through involvement in current experiments and through a strong engagement in the high-potential experiments of the coming years and decades. UK physicists carry the responsibility for key detector components and often hold leadership positions.

In Europe, UK physicists are involved in leading experiments at CERN and DESY. At DESY they are playing a strong role in the experiments H1 and ZEUS at the high energy electron-proton storage ring HERA. These experiments are presently collecting data and will be completed by mid-2007. The focus of the research is on understanding the inner structure of matter and on precision studies of the strong and electroweak forces.

At CERN, UK physicists are heavily involved in the ongoing construction of all four experiments for the LHC, as was the case in 2000. The experiments done on ATLAS and CMS will be exploiting the substantial increase of the energy frontier provided by the LHC to explore the origin of mass and shed light on physics beyond the Standard Model. The LHCb detector is dedicated to B-physics and an accurate measurement of CP violation, and the ALICE detector is a heavy ion experiment. In all experiments, UK groups carry the responsibility for major detector components and are actively involved in the preparation for the analysis of the physics. The LHC is scheduled for its first collisions in 2007 and, for years to come, will be the focal point of particle physics worldwide. The strong involvement in the experiments at the LHC will assure an effective use of the UK CERN contribution.

In the US, UK physicists are still very active in experiments at FNAL and SLAC. At FNAL, UK groups are involved in the experiments CDF and D0 at the proton-antiproton collider, Tevatron. Until the LHC turns on, this collider provides the highest collision energies and thereby a possible access to the observation of a low mass, Higgs particle. Participation in the Tevatron experiments will help the groups to make a fast start in LHC physics once the Tevatron operation ceases in around 2008. At FNAL, the UK is, in addition, active in the field of neutrino physics, in the long baseline experiment MINOS exploring neutrino oscillations. At SLAC, there is still a strong involvement in the BaBar experiment, exploration of the origin of the matter-antimatter asymmetry in nature, through the precise measurement of the parameters of CP violation in B-meson decay.

During the transition from the present generation of experiments to the LHC, care should be taken to make appropriate use of the collected data.

Particle astrophysics is a research field linking particle physics, astrophysics and cosmology and has become of growing importance worldwide. UK groups are still active in this field through several projects, ranging from a competitive search for cold dark matter and the measurement of solar neutrinos to the study of the highest energy cosmic ray particles. It is expected that involvement in this area will grow further in the coming years.

In preparation for a leadership role in the longer term future of experimental particle physics, the UK has two initiatives: first, UK groups, with funding from PPARC, are taking a leading role in all aspects related to the International Linear Collider, agreed to become the next major project in particle physics. Part of this work is embedded in a major network supported by the EU. The second initiative is an international project on muon ionisation cooling, MICE, under construction at RAL, in which the UK, together with its partners, is addressing some of the key challenges of future high intensity neutrino beams.

Major new strategic funding initiatives, either ongoing or starting in the past five years, have had a significant impact on other fields as well as particle physics. One was related to e-Science, which is providing the computing environment necessary for the evaluation of data from the LHC. The GRID computing initiative, involves 19 UK universities, CCLRC and a strong collaboration with CERN and other international partners. The GRID hardware and software technology, which is being developed by the initiative, will be of increasing importance for other fields of science, such as biology, medical image processing, and Earth observation. The GRID operation centre is based at RAL.

The other strategic funding initiative provides a significant increase in accelerator R&D and focuses on re-establishing accelerator science in the UK. Historically, the UK was very strong in accelerator development but did not maintain its leading position. Two new accelerator centres were established recently by PPARC as joint initiatives of several universities to enable the UK to resume an active role in accelerator development in the future. This initiative is being further strengthened by a new department inside CCLRC, ASTeC, which is one of the partners in this initiative. PPARC and CCLRC have obtained substantial additional funding to support this accelerator science initiative. This initiative will strengthen not only particle physics, but all of accelerator based science, such as the development of new light sources.

Progress in experimental particle physics is closely linked to progress in detection methods and the construction of detectors. It is therefore vital to provide and maintain the infrastructure necessary to enable such developments. JIF money has enabled, for example, the construction of the Liverpool Semiconductor Detector Centre, which opened in 2003.

The particle physics groups in the UK would not have been able to participate in the construction of detectors using front line technology without the strong and essential support provided by RAL.

2.5.2 THEORY

Particle theory in the UK is healthy, with a revitalised effort in particle phenomenology, a burgeoning contribution to the physics that might lie beyond the Standard Model, a strong and vital group of lattice theorists and continuing strength in string theory and general relativity.

With the founding of the IPPP, a joint venture of the University of Durham and PPARC, particle physics phenomenology in the UK has been substantially revived. The IPPP has had major successes: creating a critical mass of particle theorists in Durham. There have been very healthy interactions with formal and string theorists in the mathematics department, reviving particle phenomenology throughout the UK, and the organisation of many meetings and workshops. This development is very important, since it is essential that UK experimentalists and theorists be ready to exploit discoveries made at the LHC in the near future.

The UKQCD collaboration continues to be a world-class lattice gauge theory collaboration. UK lattice gauge theorists, who have made essential contributions to the construction of the next generation (QCDOC) supercomputer, are an important part of the HPQCD collaboration, and play a vital role in the supercomputing effort in the UK. There is increasing synergy between these computational efforts and experimentalists in heavy quark and flavour physics.

As stated in the 2000 report, the UK has a long history of excellence and leadership in string theory and general relativity. However, there are signs that this position is under threat. Therefore, it is imperative that efforts be made to attract and retain the best young theorists and to afford them opportunities. Joint efforts with mathematics departments (such as the Institute for Mathematical Sciences at Imperial College London) should be supported.

In summary, in view of its exciting scientific future, particle physics has been substantially strengthened over the past five years, which will ensure a continuation of the leadership role and high visibility of the UK.

2.6 SOFT MATTER AND BIOPHYSICS

In the UK, experimental and theoretical soft matter physics emerged as a vibrant area of research at a time when, internationally, the field was still quite small. At present, the UK has a small number of groups that are internationally prominent in the experimental, theoretical and computational study of colloids, polymers and surfactants. However, it is the perception of the Panel that there are quite a few physics departments where students get little, if any, exposure to modern soft matter physics. This is regrettable, because soft matter physics has deep links with many other areas of science, whilst the theoretical concepts and experimental techniques of this field are of direct relevance for biophysics. In addition, soft matter physics has many industrial applications. There are unique possibilities for experimental soft matter research in the UK, because of Britain's important role in facilities and related instruments at ISIS, ILL, ESRF and, in the future, Diamond.

Biophysics, which went through a phase of reorientation in the UK in the mid-1990s, has been rejuvenated during the last five years, particularly with new initiatives in the fields of single-molecule biophysics, molecular motors and nanobiotechnology. New centres were installed with well-targeted investments in both infrastructure and new, also international recruitment, creating an active link to the vividly growing UK biotechnology industry. A healthy growth of the field can be expected if support continues. The Panel found the best UK laboratories to be comparable in standing to the best biophysics laboratories in Japan or continental Europe, but still behind US centres.

The Panel observed that the majority of the internationally visible biophysics research is not conducted in physics departments, but rather in (bio)chemistry and (molecular) biology departments. The Panel recognises that research is problem driven and that, as a result, the successful groups choose the department best suited to carrying out their research. At present, the department of choice is usually not a physics department. The Panel expresses concern that this drain of physicists active in biophysical research out of physics departments, will limit the exposure of UK physics students to one of the fastest growing cross-disciplinary developments in modern physics.

Internationally, the recognition that biophysics and soft matter physics are mainstream physics disciplines is increasingly reflected in the structure of physics organisations (e.g. APS: Division of Biological Physics, DPG: Arbeitskreis Biologische Physik, EPS: Division of Physics in Life Sciences). A strengthening of interdisciplinary research within UK physics seems strongly advisable.

The Panel found that the rather rigid vertical structures in the departmental organisation of the universities are mirrored in the structure of the research councils. In particular, research at the boundary between physics and other disciplines is hampered by these structural obstacles: the research councils could foster the growth of biophysics in Britain by creating both junior and senior fellowships that require joint appointments between departments. Experience in other countries suggests that "Life Science Interfaces" are better at selecting truly exciting proposals if they have their own interdisciplinary panel. It would seem logical to do the same in Britain.

3. GENERAL FINDINGS ON PHYSICS AND ASTRONOMY

The university departments visited by the four sub-panels were quite varied. This diversity allowed the Panel to make some tentative observations about general trends in the conditions that affect physics and astronomy research. At the same time, it could be seen how differences in local circumstances affected the way in which the university departments responded to these changing conditions.

3.1 HUMAN POTENTIAL

3.1.1 YOUNG PHYSICISTS

PhD Students

The Panel was pleased to note that some of the concerns highlighted in the 2000 report pertaining to PhD students had been addressed, such as the increase in the stipend. The infrastructure money spent on new modern buildings and equipment has had a significant effect on improving the morale and research environment of the physics and astronomy community, and there has been an increase in the number of female and non-UK postgraduate students. The Panel also noted that there was a clear commitment on the part of UK funding agencies to increase the international exposure of PhD students by making adequate amounts of funds available for attendance at international conferences. The increase in the stipend to that of a living wage, in particular, has made a big difference. Several of the PhD students that the Panel spoke to indicated that they would not have been able to pursue a PhD with the old level of support and funding. However, there are still a number of issues that need urgent attention, such as the length of PhD study and the inflexibility of postgraduate education.

The Panel is of the view that a three-year programme of study, despite its advantages, for example the efficient flow of graduates into the employment market at an earlier age, is undermining the ability of UK PhD graduates to compete with their international counterparts for postdoctoral fellowships, both at home and abroad. Alarmingly, this view was shared by a number of PhD students questioned by the Panel. In addition, many of them indicated that they felt inadequately prepared in secondary school and that, even after four years of undergraduate training (i.e. MPhys/MSci degree programmes), they felt less trained than many PhD students from other EU countries.

The Panel is of the view that UK PhD students are well trained in their narrow sub-fields, but lag behind their counterparts in countries like Germany in their broad set of skills. This problem is exacerbated by the lack of graduate advanced courses, coupled with little or no credit allocated to these courses by university departments. The level of mathematical skills is also a concern, which appears to be a consequence of the falling mathematical content of secondary school physics and undergraduate degree programmes.

The Panel was encouraged to note that PPARC are funding some PhD students for up to four years, and EPSRC for three and a half years with the flexibility within a university to use the funds to provide four years of support, but would like to see both research councils fund PhD studentships for four years. The research councils are no longer penalising universities whose PhD students do not complete their training, but the Panel understands that some universities may themselves penalise departments.

In view of these comments, the Panel recommends that the UK needs to make an informed decision about the future of its graduate training programme. In order to do this, it should commission an in-depth review of graduate level education, which needs to incorporate comparisons with its leading scientific competitors, and address the implications of the Bologna Process, which proposes to introduce a common framework of undergraduate, masters and postgraduate education across Europe.

As highlighted in the 2000 report, the UK still needs to review its policy of charging higher tuition fees to non-EU students, which is resulting in it profiting less than other EU countries from the influx of intellect from countries outside the EU (in particular, south and southeast Asia). The possibilities for covering these expenses are, at present, very limited. For EU students, tuition can be waived and more possibilities exist to fund subsistence, although apparently not all of the research councils treat EU students as equals with their UK counterparts. Overseas students should be seen as an investment to the UK.

Postdoctoral Research Assistants

The situation of the perennial PDRA, going from one short-term contract to another, with the associated uncertainty is not the ideal environment in which to nurture young academic talent. The situation has not improved since the 2000 review.

Working indefinitely on short-term contracts (i.e. around 10 years and sometimes even longer) makes it more difficult to do things that are normal for others in the same age group (i.e. start a family, get a mortgage, etc). The average age of appointment to a permanent academic position, according to data provided to the Panel, is 35. This in particular, disadvantages women, resulting in only a few of them being employed in the top academic grades. This is in striking contrast to the high number of female PDRAs in the university departments the Panel visited.

A direct coupling of the term of a contract to the duration of a specific project appears to be a weak formulation. The advent of FEC, together with the introduction of the EC's fixed term work directive, makes it imperative to resolve this problem now. Universities in consultation with the research councils should do this with an eye on EC legislation.

The Panel noticed that the salaries for PDRAs have been increased, but after deductions are not significantly above the graduate student stipend. This situation may give rise to young PDRAs seeking employment outside academia, leading to a drain of the best talent. An additional concern relates to the continuation of PDRA contracts. While it is positive that the salary rises with increasing experience, concern was expressed to the Panel that more experienced, but more expensive, PDRAs were being replaced by less-experienced PDRAs at the lower end of the pay scale.

The Panel note that the RCUK Academic Fellowship scheme was introduced as a measure to counteract this problem and offer PDRAs more attractive and stable paths into academia. The Panel is uncertain of the impact of this scheme, but restate the recommendation of the 2000 report that there needs to be greater flexibility in postdoctoral salary structures, in order to retain the very best individuals in British academia.

EPSRC and PPARC Advanced Fellowships have had a positive effect. The Advanced Fellowships serve the best PDRAs, creating a high degree of competition, which has led to a healthy number of young lecturers. But the Panel is deeply concerned whether there will be sufficient permanent academic positions in 5 to 10 years time, to accommodate the young talent in the pipeline that has been established since 2000.

EU networks offer unique opportunities for UK PDRAs. To the Panel's surprise, it found that many students and PDRAs were hesitant to apply for positions at EU universities because of a perceived language barrier. UK participation in international projects (e.g. ESRF, ILL, CERN, ESA, etc) is important because these institutions are at the cutting edge scientifically. The Panel found clear evidence that the large influx of non-UK PDRAs had been very beneficial for the competitiveness of physics and astronomy research in UK universities.

An additional point of concern is that the EU rules for overheads on PDRA positions appear to be incompatible with the rules for FEC. It is crucial that this issue is resolved, the more so as EU research grants are likely to become even more important with the advent of the European Research Council.

Funding for Non-academic Technicians

Highly skilled technicians with long-term experience in the field are a crucial enabling factor for top-level experimental physics. The Panel noted with concern that the employment of such personnel was often tied to the length of specific (often short-term) projects, which led to short-term contracts over significant periods of time. This clearly is not an incentive for the most innovative minds to work with the physics research community, and is a particular problem for fields such as space or astrophysics where long-term projects make prior experience even more invaluable. Both the universities and the research councils should seek solutions to develop career structures and secure the long-term employment of such personnel.

3.1.2 PHYSICS IN SECONDARY SCHOOLS

Both the methods and results of physics and astronomy research have an impact on society that clearly transcends the confines of academic research. However, a society can only value the importance of such research if secondary schools offer a basic education in mathematics and the core sciences, i.e. physics, chemistry and biology. As was the case in 2000, many of the individuals that the Panel encountered expressed serious concerns about the level of science education and, in particular, about the inadequate training in mathematics. In fact, many schools no longer provide the level of training in physics and mathematics that is required to enter a university programme in physics. As a consequence, a substantial fraction of those who enter university are, effectively, barred from taking up physics. This has created an unhealthy situation for a country with an increasingly knowledge-based economy.

Obviously, the problems with secondary school education have consequences for the undergraduate curriculum of physics and astronomy departments: the transition to a four-year undergraduate programme is widely perceived as a necessary change to include "remedial" teaching in the first year. Hence, the physics proficiency of the new four-year graduates is barely equal to that of the three-year graduates of 20 years ago.

3.1.3 UNDERGRADUATE EDUCATION

The Panel is of the view that physics has a unique place in a knowledge-based society, as a discipline that underpins the other core sciences and engineering. The Panel is deeply concerned to learn that since the abolition of the binary divide between universities and polytechnics, over 30 per cent of the UK's physics and astronomy departments have either closed or merged, resulting in physics ceasing to be an identifiable discipline in a number of UK universities. A continuation of this trend would threaten the UK's ability to produce the volume of physics graduates needed for it to compete on an international basis. The Panel is disturbed to find that the financial health of university departments is to a significant degree dependent on undergraduate numbers, which themselves depend on career choices of young people in the secondary system. This is not a good basis for strategic planning of the science base.

3.1.4 WOMEN IN PHYSICS AND ASTRONOMY

Overall there appear to have been successful efforts in the past five years to address the low participation of women in physics, as noted in the 2000 report. While the effort to increase the number of 12 to 14 year-old school girls studying physics is important in its own right, it is still necessary to address the structural problem of the late age (over 35) when physicists, on average, obtain permanent positions. This late age imposes unique difficulties on women with aspirations of combining a physics career and a family.

Even though, according to data provided to the Panel, the number of women employed at the professorial level in physics departments has increased from 1 to 4 per cent since the 2000 review, the Panel noted that in many departments, there are no female faculty, which is a sorry state of affairs. The Panel is of the opinion that every department should have an aspirational target of employing at least two female academic members of staff on its faculty by the end of the decade. To achieve this goal, special focus to attract (and subsequently to retain) women into science is needed from the very early stages onward.

3.2 UNIVERSITY INFRASTRUCTURE

Wherever the Panel visited, it saw an indication that JIF and SRIF were a great success, and that as far as it could tell, the funds allocated via the schemes were wisely spent, for example, on nanoscience laboratories, modern clean rooms and equipment.

Now that physics and astronomy departments have had a boost, the Panel is concerned about what will happen after the third round of SRIF finishes after 2008 – it is imperative that the momentum of funds provided for infrastructure improvement continue at the current level.

3.3 THEORY

It is the Panel's perception that there are fewer theorists in UK physics and astronomy departments than is the international norm, as was the case in 2000.

Mathematics departments take up some of the load, but it is not an ideal situation for both the theorists and their potential experimental colleagues. The situation is exacerbated by the observation that mathematics departments do not commonly participate in the mathematics teaching of physics students.

Theoretical physics has not benefited substantially from the recent investments in infrastructure and the increases in funding. A noticeable exception is the strong revival of particle physics phenomenology with the founding of the IPPP. Similar efforts should be contemplated to reverse the noticeable decline in world-class leadership in hard condensed matter, soft condensed matter, and formal theory (field theory, relativity and string theory). To this end, the role of theoretical research should be included as part of the review of graduate level education.

3.4 FACILITIES

3.4.1 CENTRAL

The central laboratories at RAL and Daresbury exist to provide infrastructure and support for large projects. The Panel believes that they play a crucial role in enabling projects that are too large for universities.

Since the 2000 review, a number of structural changes have been implemented at CCLRC as a result of its quinquennial review. New, core baseline funding has been put in place and CCLRC was given a new strategic role as the national focus for large-scale scientific research facilities for neutron scattering, synchrotron radiation and high power lasers. The Panel recognises that it is essential for the UK to have a high level strategic approach to large-scale facilities. It is important, however, that a wider strategy pays due attention to the interface between the facilities and university groups.

The 2000 review commented that the "mode of access to central facilities (ticket system) is not optimal." The Panel notes that the ticket system has now been abandoned.

The Panel was pleased to observe that money has been invested to enable CCLRC to sustain world-class facilities. ISIS is a user facility providing pulsed beams of neutrons and muons. It is currently undergoing a major expansion with the construction of a second target station. This facility, alongside Diamond, a third generation 3 GeV synchrotron light source which will produce X-ray, infrared and ultraviolet beams of exceptional brightness, will provide unique opportunities in areas including soft condensed matter, biomolecular sciences and nanoscale science. Vulcan remains a world-leading facility for performing high intensity laser experiments.

CCLRC is also playing an important role in the UK's e-Science programme, through the GRID operation centre, and is a key partner in the important initiative to develop expertise in accelerator R&D through ASTeC.

The Panel spoke to users of these facilities and gained the impression that access for UK researchers, though competitive, was good. The Panel heard concerns from the users that there had been a reduction in the number of graduate students associated with the use of central facilities. This is unfortunate, as world-leading international facilities provide a unique training opportunity for students.

3.4.2 INTERNATIONAL

Large research facilities in physics, astronomy, and space science are increasingly organised, funded and operated at an international or world level. The UK has been a long-standing member of several European facilities (CERN, ESA, ESRF, ILL, etc) and has recently joined ESO. The UK plans to continue this development through possible involvements in European projects, for example in nuclear physics (e.g. the FAIR project at GSI) and in an X-ray Free Electron Laser, and, on a longer timescale, through an active role in the International Linear Collider. These investments should be carefully balanced with national funding targeted at the exploitation of the opportunities provided by these facilities.

The international facilities are complemented by nationally funded facilities, such as ISIS (and in the future Diamond), which are also being used by scientists from other countries.

CERN, through the LHC, provides a unique research facility. UK particle physics is well positioned to make very effective use of this frontier accelerator complex. The strong involvement in the experiments at the LHC will assure an effective use of the UK CERN contribution.

The UK is a large contributor to the ESA programme, and participates in large solar system and astrophysics programmes both through ESA and through collaboration with NASA and other major space agencies. The large financial investments in the ESA programme should be carefully balanced with national funding that enables the research groups to develop instruments and analyse data from these satellites to ensure maximal output from the investment. In 2002, the UK joined ESO, which has opened access to a whole new range of ground-based facilities to the scientific community. The UK community has taken an active role in ESO programmes, but the scientific output of ESO-activities should be carefully monitored.

3.5 RESEARCH ASSESSMENT EXERCISE

As with the 2000 review, the Panel decided not to offer any comments on the mechanism of the RAE.

The main issue of concern for the Panel relates to the impact the RAE has had on departmental appointments. The RAE has made it more attractive for departments to make opportunistic "star" appointments, rather than consider the balanced growth of the department, to the detriment of indigenous young talent. Even though the Panel was pleased to see a good mixture of UK and non-UK academics at the university departments it visited, it is concerned about the long-term prospects of the UK's PDRAs in particular, who face great competition for academic and industrial positions, both at home and abroad.

3.6 RESEARCH COUNCIL FUNDING

Curiosity-driven research is important in its own right and attracts the most able people into physics and astronomy, but it is also the foundation for the improvement of quality of life and wealth creation in a knowledge-based society. The Panel has noted that some new money entering the science base has been tied up with specific initiatives. Many of these initiatives may be of strategic importance to the UK. However, the Panel is concerned that this could be a creeping trend that would undermine the opportunities of physicists and astronomers to follow their instincts in research, and the UK's ability to pursue curiosity-driven research at the highest level. The Panel recommends that the research councils monitor the balance between targeted and curiosity-driven research and maintain a healthy balance between the two funding streams.

Innovative basic research requires a long planning horizon, often exceeding a three- to four-year period. The Panel observed that this appears to be the normal funding period for grants within EPSRC (only a small proportion of PPARC grant funding is provided through short fixed-term grants) and that it is sometimes difficult to obtain continuation funding. The Panel urges EPSRC to establish mechanisms to support the most innovative and challenging research for longer time periods. Without such support, it will be difficult for the very best to remain competitive with their counterparts from other leading scientific nations.

3.6.1 RESPONSIVE MODE

There is some unease about the current system of "responsive mode" funding within EPSRC, although the basic idea behind this funding scheme is widely supported. The problem is that when the perceived success rate, for proposals submitted through this channel is very low, the whole system can become unstable: referees are unwilling to make critical comments, proposers are unwilling to propose high-risk research, and as more proposals get rejected, even more are submitted. This situation poses a strain on the organisation of the research councils and it wastes the time of the proposers, referees and grant panel members. If left unchecked, this problem may worsen with the implementation of FEC. A possible way to decrease the burden on all involved is the use of (short) pre-proposals.

It is essential to consider new strategies that would enhance the success rate of excellent high-risk proposals. In particular, the Panel recommends that the research councils should aim to ensure that high-risk research in new topics or entirely new fields (those emerging in the UK without strong international background) should have resources for appropriate funding. One option is for the research councils to facilitate the entry of individuals, who have made important contributions to one research field, into another field where they are not yet recognised experts.

3.6.2 PORTFOLIO GRANTS

EPSRC's portfolio grants are another (already existing) tool to reduce the burden of paperwork on the peer review process, and stimulate high-risk research, which the Panel highly commend.

3.6.3 MANAGED PROGRAMMES

Managed programmes can play an important role as a response to new developments and/or as a means to enable collaboration between two disciplines. This approach is particularly relevant in the UK, where departments are organised as "stand-alone" units. One drawback of the present managed programmes is that there is insufficient transparency in the selection of themes. More transparency is called for because the formulation of the scientific aims of a managed programme determines what project proposals stand a good chance of being funded. In addition, the present procedures may simply be too time consuming.

Overall, the Panel echoes the sentiment of the 2000 report that managed programmes should be used with restraint and not at the expense of responsive mode funding.

3.6.4 ROLLING GRANTS

For long-term research programmes, rolling grants offer a possibility for continuing support of the research group. They are especially valuable in research, where the results come after only years of intensive work either on experimental set-up or developing theoretical concepts. Such grants provide a means to support creative, even high-risk research without unnecessary micromanagement, and with a low degree of bureaucratic overhead. The Panel strongly endorses the use of rolling grants for top-tier groups and individuals.

3.6.5 INTERDISCIPLINARY RESEARCH

New developments in science often take place at the interface between existing disciplines. The Panel noted that the amount of interdisciplinary research in the UK is low, and where it does occur, the quality does not always meet the highest standards. Furthermore, interdisciplinary research did not appear to be valued either by the research community or by the funding agencies. The physics community needs to open up to more interdisciplinary work. It was noted that while the interaction between, for example, physics and biology does occur, it is driven by the biologists resulting in many biophysicists working outside of physics departments. This trend is damaging for the development of physics in the UK.

Biophysics is an exciting area that needs to overcome funding and institutional barriers. The research councils need to provide special incentive programmes for cross-disciplinary research in physics and biology to break down the barriers between the disciplines, which will encourage the best people in their fields to seek research partners in other university departments, and propose collaborative funding. A good start would be to form joint proposal review panels (EPSRC's Life Sciences Interface Programme is a move in the right direction – although it should have its own interdisciplinary panel).

The Panel does not believe that the managed programme mechanism is the right way of supporting this research. Rather, that flexibility must be created within the research council's existing responsive mode funding route to recognise and accommodate high-quality interdisciplinary research proposals.

3.6.6 KNOWLEDGE TRANSFER

The Panel has noted that the research councils have been promoting knowledge and technology transfer through their knowledge transfer schemes, and have many success stories such as CDT at Cambridge and within the SUPA collaboration. The Panel is of the view that UK plc would greatly benefit by having similar activities throughout the country.

3.7 FULL ECONOMIC COSTS

The Panel gives a cautious welcome to the introduction of FEC, but is concerned that it could lead to a potential diminution in the volume of research the UK conducts. The Panel trusts that the impact of FEC will be monitored closely and recommends that contingency funds be in place if it becomes evident that support for research is being undermined.

APPENDIX A

DATA SUPPORTING THE REVIEW

All members of the Panel were provided with the following documentation:

1. BACKGROUND INFORMATION AND DATA DOCUMENT

This is a substantial body of data on the funding, staffing and outputs of physics and astronomy research throughout the university and research council sector, collected and collated by the Secretariat. The contents of this document are listed below:

- Organisations of and policies for science in the UK
- Funding of research in the UK
- The funding councils
- The research councils
- Spending Review 2004
- Funding of physics research in the UK
- Funding provided by EPSRC
- How EPSRC allocates its funds
- Support for physics research projects
- Support for research students and fellowships
- Funding provided by PPARC
- How PPARC allocates its funds
- PPARC funding
- International subscriptions
- PPARC overseas facilities
- PPARC UK facilities
- PPARC statistics
- The Research Assessment Exercise
- RAE 2001: Panel comment on the physics submissions to the RAE
- How HEFCE allocates its funds
- Quality-related research funding
- Mainstream quality-related funding
- People in physics
- Post-16 statistics
- First degree statistics
- Graduate statistics
- Academic staff
- Numbers of university staff and age profile of the academic community
- Gender breakdown of the physics academic community
- Important reports published since 2000
- Acronyms

2. KEY ISSUES PAPER

This paper used the 2000 report as a baseline, to highlight the key changes that have taken place in the science base, and the individual sub-fields of physics and astronomy on which the 2000 international panel commented, and suggested recommendations for support and improvement. The contents of this document are listed below:

- Introduction
- The Organisation of UK Science, Engineering and Technology Research
- UK Government Strategy for Investing in Science, Engineering and Technology
- International Reviews
- Findings of the International Review of UK Physics & Astronomy Research 2000

3. SITE VISITS

In order to provide contextual information to support the Review, the Panel visited a selection of university physics and astronomy departments in the UK. The Panel was split into four sub-groups, each of which visited universities as highlighted in the introduction to this report. The universities were selected to illustrate substantial research departments (RAE 2001 grades 4, 5 and 5*) and to illustrate the regional diversity of physics and astronomy research departments. In addition, the Panel visited the CCLRC Rutherford Appleton Laboratory.

To support the site visits, the university departments were requested to complete the following data template, in order to provide information and statistics on the department's physics and astronomy research as well as providing an insight into their research priorities.

INTERNATIONAL REVIEW OF PHYSICS AND ASTRONOMY 2005

UNIVERSITY DEPARTMENT DATA TEMPLATE

Institution

Head of Department
(including phone number)

Departmental Strategic Vision Statement (200 words max.)

Departmental Research Themes (and main contact for each)

Key Research Highlights over the last five years

Major Changes since the 2000 International Review of Physics and Astronomy

Research Facilities (run for departmental use or as national/regional facilities)

Key Collaborators (academic and non-academic, including international)

Graduate Student Research Training Activities

Departmental Statistics

Number of People and Research Income for Each Research Theme

Research Theme	Academic Staff	PDRAs	Research Students	Technical Staff	Annual Expenditure*

(*expenditure for the last full year, financial or academic, for which you have figures)

Funding Sources (2004 to present; including non-research council sources)

Age Profile and Gender Balance of Academic Staff

Age	Number of Academic Staff	% Male Staff	% Female Staff
25-34			
35-44			
45-54			
55-64			
65+			

Current RAE Grade

Publications Record

Number of Publications (2004 to present)

Publication Highlights (2004 to present)

4. QUESTIONNAIRE

A questionnaire, identical to the one employed in the 2000 review, was sent out by the Panel to 15 or so of their non-UK colleagues, with the aim of providing the Panel with a broad-based view of the quality of UK research being undertaken in their particular sub-fields.

Overall, the Panel was of the view that the responses generally matched with their own personal perceptions.

APPENDIX B

METHODOLOGY FOR THE SITE VISITS

The following guidelines were sent to the university departments prior to the Review:

UNIVERSITY DEPARTMENT VISIT GUIDELINE DOCUMENT

The sub-panel visits should address among other issues, funding difficulties, barriers to success, threats and opportunities for the future, as well as showcasing high quality research.

It is the responsibility of the head of department to ensure that all research groups in the department of physics (and astronomy) are represented at the sub-panel visits.

Each individual department will respond to the visits in a way that matches its particular characteristics, but it is suggested the following areas should be covered.

1. A strategic overview of the department, its structure, research areas and plans for the future.

2. Discussion sessions with group leaders and senior staff on their research programmes.

3. Tours of the laboratories.

4. A private session with PDRAs and PhD students.

5. An opportunity to talk to non-research staff key to the research infrastructure, for example senior technicians.

6. Sessions with key individuals outside the physics and astronomy department, in order to provide a picture of the department's relationships with other departments and the central administration.

The visits should be as informal as possible so that there are no barriers to frank discussion between the sub-panel members and departmental staff, i.e. formal presentations should be short to allow for discussion. Discussion should take place in the work place and not in formal lecture theatres where possible.

We would suggest that dinner would provide the opportunity for people from outside the department to be involved and similarly lunch would provide the opportunity for the sub-panel to meet with non-academic staff.

A sample visit might be structured as follows:

PREVIOUS EVENING

19.30 **Dinner** with senior university staff, including the vice-chancellor, pro vice-chancellors and staff from other disciplines. If, as a result of travel delays, the sub-panel arrive too late for the dinner, then the head of department and other senior staff could attend a breakfast meeting with the sub-panel at their hotel.

DAY OF VISIT

09.00 **Introduction** from the head of department allowing time for questions. Senior academic staff to be present.

09.30 **Series of mini-tours** of the department to include 10-minute presentations from group leaders.

11.00 **Coffee** break.

11.15 **Private session with PDRAs and PhD students.** Part of this session could be with posters or with short research presentations. Informality would be best achieved without the presence of permanent academic staff.

12.30 **Lunch** – an opportunity to invite staff not seen by the sub-panel.

13.30 **Further tour** of research groups.

14.30 **Wrap-up session** with all staff present where questions arising during the day can be addressed.

14.45 **Private session** with the head of department.

15.00 **End**.

APPENDIX C

THE REVIEW WEEK

Sunday, 30 October

19.30	Welcoming dinner for Panel.

Monday, 31 October

09.00	Introduction and welcome – Professor Peter Main, the Institute of Physics. Background presentations – Professor John O'Reilly, EPSRC; Professor Keith Mason, PPARC; and Professor Sir John Pendry, RAE 2008 physics sub-panel.
11.00	Panel – working sessions.
15.30	Sub-panel groups travel to first set of university departments.

Tuesday, 1 November

09.00	Sub-panel groups undertake formal departmental visits.
15.00	Sub-panel groups travel to second set of university departments.

Wednesday, 2 November

09.00	Sub-panel groups undertake formal departmental visits.
15.00	Sub-panel groups return to London. Evening off.

Thursday, 3 November

09.00	Panel visit RAL.
14.00	Panel working session at RAL.
19.30	Working dinner for Panel in London.

Friday, 4 November

09.00	Panel meeting and drafting of report.
15.00	Meeting of Panel with representatives of the Steering Group and the Secretariat. This meeting to act as a "feedback session and sounding board" for the report's primary conclusions.
17.00	Formal thanks. Panel members depart.

APPENDIX D

THE PANEL

Professor Jürgen Mlynek
Helmholtz Association, Germany
(Chair)

Research area: experimental – quantum optics, atomic physics, and nanoscience

Professor Roger Blandford FRS
Stanford University, USA

Research area: cosmology, black hole astrophysics, gravitational lensing, galaxies, cosmic rays, neutron stars, and white dwarfs

Professor Richard Casten
Yale University, USA

Research area: nuclear physics

Professor Mildred Dresselhaus
Massachusetts Institute of Technology, USA

Research area: experimental condensed matter physics, and nanoscience

Professor Stephen Forrest
Princeton University, USA

Research area: photonic materials, devices, and systems

Professor Daan Frenkel
University of Amsterdam, and FOM Institute for Atomic and Molecular Physics, the Netherlands

Research area: computational physics, and soft condensed matter

Professor Hermann Gaub
Ludwig-Maximillians Munich University, Germany

Research area: biophysics, and molecular materials

Professor David Gross
University of California, Santa Barbara, USA
Nobel Prize Winner in Physics 2004

Research area: high energy physics, quantum field theory, and string theory

Professor Massimo Inguscio
University of Florence, Italy

Research area: atomic physics, radiation-matter interaction, and quantum degenerate gases

Professor Sir Anthony Leggett FRS
University of Illinois at Urbana-Champaign, USA
Nobel Prize Winner in Physics 2003

Research area: theoretical condensed matter physics, low temperature phenomena, quantum fluids, statistical physics, macroscopic quantum systems, and quantum theory of measurement

Professor Tuija Pulkkinen
Finnish Meteorological Institute, Finland

Research area: space plasma physics, planetary physics, and geophysics

Professor Govind Swarup FRS
National Centre for Radio Astronomy, India

Research area: radio astronomy

Professor Albrecht Wagner
German Synchrotron Research Centre (DESY), Germany

Research area: experimental particle physics

Professor Anton Zeilinger
University of Vienna, Austria

Research area: foundations of quantum mechanics, matter wave interference, quantum information theory and experiment, and quantum computation

APPENDIX E

ACRONYMS

AGATA	Advanced Gamma Tracking Array
ALICE	A Large Ion Collider Experiment
ALMA	Atacama Large Millimetre Array
APS	American Physical Society
ASTeC	Accelerator Science and Technology Centre
ATLAS	A Toroidal LHC Apparatus
BaBar	B and B-bar experiment
CCLRC	Council for the Central Laboratory of the Research Councils
CDF	Collider Detector at FNAL
CDT	Cambridge Display Technology
CERN	Conseil Européen pour la Recherche Nucleaire (European Laboratory for Particle Physics)
CLOVER	A cosmic microwave background polarisation experiment
CMS	Compact Muon Solenoid Detector
CNO	Carbon-nitrogen-oxygen
D0	Experiment at FNAL
DESY	Deutches Elektronen Synchrotron Laboratory (German Synchrotron Research Centre)
DPG	Deutsche Physikalische Gesellschaft (German Physical Society)
ELT	Extremely Large Telescope
EPS	European Physical Society
EPSRC	Engineering and Physical Sciences Research Council
ERC	European Research Council
ESA	European Space Agency
ESO	European Southern Observatory
ESRF	European Synchrotron Radiation Facility
EURISOL	European Isotope Separation On-Line Radioactive Ion Beam Facility
EXOGAM	Exotic Gamma (spectrometer)
FAIR	Facility for Antiproton and Ion Research
FEC	Full Economic Costs
FIRST	Far Infrared Space Telescope
FNAL	Fermi National Accelerator Laboratory
GANIL	Grand Accélérateur National d'Ions Lourds
GREAT	Gamma Ray Electron Alpha Tagging (spectrometer)
GSI	Gessellschaft für Schwerionenforschung
H1	Collider experiment at DESY
HEFCE	Higher Education Funding Council for England
HERA	Hadron-Electron Ring Accelerator
HESS	High Energy Stereoscopic System
HPQCD	High Precision Quantum Chromodynamics
ILL	Institut Laue-Langevin
IOP	Institute of Physics
IPPP	Institute for Particle Physics Phenomenology
IRC	Interdisciplinary Research Centre

ISOL	Isotope Separator On-Line
ISOLDE	On-Line Isotope Mass Separator
JCMT	James Clerk Maxwell Telescope
JIF	Joint Infrastructure Fund
JLab	Thomas Jefferson National Accelerator Facility
JUROGAM	Gamma Ray spectrometer in Jyvaskula, Finland
LHC	Large Hadron Collider
LHCb	Large Hadron Collider beauty experiment
LIGO	Laser Interferometer Gravitational Wave Observatory
MAMI	Mainz Microtron, Institute for Nuclear Physics
MPhys/MSci	Four year undergraduate degree in physics
MERLIN	Multi-Element Radio-Link Interferometer
MICE	Muon Ionisation Cooling Experiment
MINOS	Main Injector Neutrino Oscillation Search
NUSTAR	Nuclear, Structure, Astrophysics and Reactions
NASA	National Aeronautics and Space Administration
NPL	National Physical Laboratory
PDRA	Postdoctoral Research Assistant
PPARC	Particle Physics and Astronomy Research Council
QCD	Quantum Chromodynamics
QCDOC	QCD on a Chip
QED	Quantum Electrodynamics
QIPIRC	Quantum Information Processing Interdisciplinary Research Collaboration
RAE	Research Assessment Exercise
RAL	Rutherford Appleton Laboratory
RAS	Royal Astronomical Society
RCUK	Research Councils UK
RHIC	Relativistic Heavy Ion Collider
RISING	Rare Isotope Spectroscopic Investigations at GSI
SACRED	Silicon Array for Conversion Electron Detection
SCUBA-2	Submillimetre Common-User Bolometer Array (second generation)
SET	Science, Engineering and Technology
SLAC	Stanford Linear Accelerator Center
SKA	Square Kilometre Array
SPIRAL	Systeme de Production d'Ions Radioactifs et d'Acceleration en Ligne
SRIF	Science Research Infrastructure Fund
SUPA	Scottish Universities Physics Alliance
TIARA	Transfer and Inelastic All-angle Reaction Array
TIGRESS	TRIUMF-ISAC Gamma Ray Escape Suppressed Spectrometer
TRIUMF	TRI-University Meson Facility
TUDA	TRIUMF-UK Detector Array
UKQCD	UK Research Collaboration in Quantum Chromodynamics
VAMOS	Variable Mode Spectrometer
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
ZEUS	Collider experiment at DESY's HERA

THE INSTITUTE OF PHYSICS is a leading international professional body and learned society, with over 35,000 members, which promotes the advancement and dissemination of a knowledge and education in the science of physics, pure and applied.

THE ENGINEERING AND PHYSICAL SCIENCES RESEARCH COUNCIL (EPSRC) is the UK government's leading funding agency for research and training in engineering and the physical sciences, investing around £500 million a year in a broad range of subjects – from mathematics to materials science, and from information technology to structural engineering.

THE PARTICLE PHYSICS AND ASTRONOMY RESEARCH COUNCIL (PPARC) is the UK's strategic science investment agency. By directing, co-ordinating and funding research, education and training in particle physics and astronomy, PPARC delivers world-leading science, technologies and people for the UK.

THE ROYAL ASTRONOMICAL SOCIETY is the UK's leading professional body for astronomy & astrophysics, geophysics, solar and solar-terrestrial physics, and planetary sciences.

Advancing Astronomy and Geophysics

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