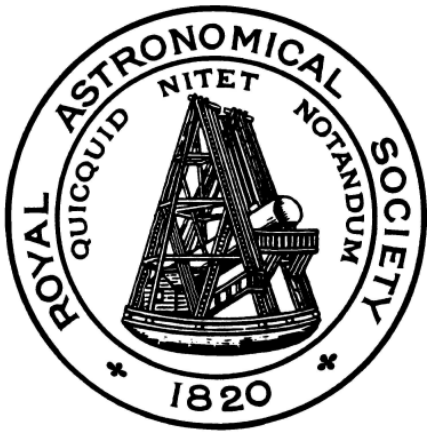

Evidence for the Wakeham Review of the Health of Physics: Submission by the Royal Astronomical Society

22 May 2008

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Summary

This report brings together the evidence assembled by the Royal Astronomical Society (RAS) to inform the Wakeham Review of the Health of Physics. Our submission concentrates on the areas of astronomy and space science (which includes some of the research areas our Fellows identify as geophysics).

The evidence in the report is divided into the areas requested i.e. astronomy's role in promoting study and careers in physics, the international position of the UK compared with the US and other EU nations and the visible economic benefits of basic research in this area.

We have used a range of sources, including Government agencies (e.g. BNSC), published research and direct surveys of Fellows of the RAS.

Our evidence indicates that:

- Astronomy and space science are effective in bringing students to further study and careers in Science, Technology, Engineering and Medicine (STEM) subjects
- UK researchers working in astronomy and space science are more productive than in any other country with the exception of the US
- Funding for basic research in astronomy and space science is relatively low compared with other EU states
- The survival of a number of UK physics departments depends on a strong research record (and the ability to attract funding) in astronomy and space science
- Where applications exist, UK astronomy and space science research groups have a good record of developing spin-out companies
- Graduates with astronomy qualifications pursue a range of careers and bring considerable added value to the UK economy

The Funding of UK Astronomy

Astronomy and Space Science in the UK are funded principally by the Science and Technology Facilities Council (STFC). In the past astronomy was in the Science Research Council (SRC) and then the Science and Engineering Research Council (SERC), so in the same council as the rest of physics. Only with the creation of the Particle Physics and Astronomy Research Council (PPARC) and the Engineering and Physical Sciences Research Council (EPSRC), then the STFC, have astronomy and particle physics been separate. The decisions about this evolution of council have largely been imposed from above by government and were not instigated by astronomers.

Being a curiosity-driven basic science, astronomy is unusual compared to many other sciences in having little in the way of an applied side.

Astronomy is a coherent science with most research papers in the world appearing in just four journals (ApJ, AJ, MNRAS and A&A) and 3 others taking much of the rest (Icarus, Solar Physics and JGR). It creates wide public and media interest, which astronomers are keen to support.

The operation of STFC, at least from an astronomy and space science point of view, seems far from optimal given the events of the past 6 months. It is sensible that the funding of facilities (telescopes etc) be within the same Council as the funding of the grants to use those facilities. To a first approximation, astronomers are both the producer and the customer of their work. There is widespread feeling that astronomers should have more direct control of the strategy and direction of astronomical research carried out by the UK and that peer review and funding decisions are made in a transparent way in accordance with the agreed strategies. The introduction of new projects and the phasing out of old ones needs to be planned well in advance in a way that is subject to peer review by a wide range of experienced astronomers. The management of the funding of astronomy is more important than the name of the research council.

Much of the funding goes into large facilities and their use, but UK astronomers have long shown strong leadership in theory and modelling of astronomical objects and phenomena. The grants line which funds this effort, together with the use of the facilities, needs to be protected from the large fluctuations in financial pressure that often occur due to overruns etc in the large facilities and exchange rate, which affect the cost of subscriptions to ESA, ESO etc.

The size of the UK Community

UK astronomy is second only to the US in terms of numbers of publications and citations over the past decade or so. It is not however so far ahead of our nearest rivals such as Germany and France that we can be complacent. As a percentage of GDP (discussed later) the number and funding level of UK astronomers is unexceptional.

Astronomy has been seen as an appealing area for expansion by some Universities and physics departments. It attracts undergraduates into physics (most physics degrees in the UK offer at least some astrophysics), adds diversity of funding source (STFC as well as EPSRC) and offers strong future potential for participation in exciting areas. It is also attractive since small groups of astronomers can intellectually lead small observing projects on world class telescopes overseas, or theory projects, and need not require laboratory space.

An expansion in the number of astronomers has occurred over the past decade in a manner which has not been coordinated between universities and groups. The move of physicists into astronomy has not been tracked by the funds those physicists had previously called upon. It is not clear that it can or should expand much further if funding remains at its current limit. A long-term perspective on the viability and stability of small groups is required.

The role of space science and astronomy in attracting students to further study and careers in Science, Technology, Engineering and Medicine

Astronomy and space science have long been cited as factors encouraging a positive view of physics and more generally attracting students to further study and careers in Science, Technology, Engineering and Mathematics (STEM) subjects. Recent studies such as the 'Case for Space' (Spencer & Hulbert, 2006) and 'Bringing Space into School Science' (Barstow, 2005) collected evidence for the STEM attractor hypothesis, particularly at school level, looking at qualitative and quantitative measures of the impact of exposure to outreach / education in astronomy and space science.

Influence at school level

Barstow referred to work by Osborne and Collins (2000) which examined pupils' and parents' views of the science curriculum, concluding that the study of astronomy and space was the one topic which generated universal enthusiasm. Jarvis and Pell's (2002) and (2005) studies looked at the impact of visits to the National Space Centre in Leicester and measured the attitudinal change of participants at intervals following their visit. They found a clear positive effect on pupils' views of science, even some months later. Blackwood's study of Scottish Space School participants (2006) found a long-term effect, with half of those participating reporting that the experience directly influenced their decision to follow a STEM-related university course or career.

Spencer and Hulbert noted the anecdotal nature of much of the evidence but given their diversity of witnesses nonetheless believed it to be compelling. They collated responses from teachers, other education professionals and specialists in industry.

At primary school level, space and astronomy were described as the most popular themes (along with dinosaurs) in the classroom.

At secondary level, a number of teachers have collected data indicating that teaching space topics has a significant and measurable impact on pupil achievement (for example Anu Ohja, an Advanced Skills Teacher at Perry Barr High School has done this for 10 years). In St Peter and St Paul's High School in Widnes, introducing a space module led to an increase in AS Physics from 4 to 17 applicants from 2000 to 2001 (Spencer & Hulbert, 2006).

Bridging school-based and adult education, one of the few sub-degree qualifications in astronomy and space science is GCSE Astronomy, a course which followed the introduction of O level Astronomy in the 1980s. In the early 1990s this attracted around 250 applicants a year but now more than 1200 elect to study this (optional) course with much of this increase being in the state school sector (data from EdExcel and (Williams, 2008)). This is quantitative evidence of the enduring popularity of the subject at secondary school level.

Distance learning and adult education

A number of higher education institutions offer distance learning and non-formal adult education courses in astronomy.

The RAS recently surveyed taught astronomy provision in UK universities (2008) and asked about this offer. A number of universities have this provision, with the obvious leader being the Open University. In many cases students on these courses go on to follow full degree pathways.

Examples include Glasgow University, which ran 5 courses in 2007/2008, ranging from a 1-day class on astrophotography to 10-week courses on stellar evolution and "Einstein's Universe". Liverpool John Moores University recruit around 200 students each year to distance learning courses leading to a Certificate of Professional Development. Finally, Queen Mary University of London runs a 1-week residential astronomy course for physics teachers, annual Master Class public lectures and an introductory certificate in astronomy and astrophysics.

Influence at undergraduate level

Many universities offer undergraduate courses relating to astronomy, partly with the intention of attracting students to study degree pathways in physics. The Universities and Colleges Admissions Service (UCAS) keep statistics of applications and acceptances to UK undergraduate courses and these indicate a slight growth (3.8%) in the number of students opting to study physics at undergraduate level in recent years.

A number of admissions tutors and senior academics see astronomy as the key to attracting students to pure physics degree pathways and other STEM courses. In the RAS survey respondents cited the way in which including astronomy elements in a broader degree course makes that course more attractive to prospective students.

Students taking pure physics pathways commonly elect to take astronomy courses within them and often make up the majority of those in attendance. The subject also draws in students in unrelated areas. For example, in our survey one university reported that 150 students taking disciplines other than physics elect to take modules in astronomy and it is seen as a useful vehicle for teaching broader scientific techniques.

Applicants also often cite an interest in astronomy on a UCAS application form, even when they do not intend to take an undergraduate degree in the subject. Respondents to our survey believe that it has helped stem the long decline in numbers electing to study physics at this level. At one institution 95% of first year undergraduates cited astronomy and particle physics as significant factors that motivated them to apply to study physics. At another applications have risen strongly over the last two years (by around 25% each year) and this is

attributed to the strength of the astrophysics research group and the resulting high profile of the physics department.

In 1995 PPARC carried out its most recent survey of physics undergraduates and considered the motivation of students. Some 55% cited astronomy, astrophysics, cosmology and space research as a major influence on their choice of subject. This represented an increase on the value for the 1984 survey and even allowing for the lack of data over the last 13 years, there seems no obvious reason to doubt that these subjects are significant in drawing students into physics.

This view is shared by figures in private industry and education, some of whom are quoted in Spencer and Hulbert's report. Their examples include engineers at BAE and a school Physics teacher as well as PhD students in engineering and astronomy. They also refer to a survey of 500 members of the Institute of Mechanical Engineering (IMechE), of whom 27% said space significantly influenced their career choice and 78% believed it to attract young people to STEM subjects.

Activity by UK astronomy and space science research groups

Physics departments' dependence on astronomy funding

There are more than 40 research groups in the UK that carry out work in the areas covered by the RAS remit. These vary from established universities with long track records, such as Imperial College, Oxford and Cambridge to a few more recent post-1992 universities such as Liverpool John Moores that have seen a great expansion in activity in the last 15 years.

Many institutions have established astronomy research groups and undergraduate degrees as a means of attracting students, with the number doubling in the past two decades.

To provide information for the CSR settlement 2007-10, the RAS analysed the research income streams for each of 40 institutions to establish their dependence on astronomy funding from the then Particle Physics and Astronomy Research Council (PPARC) in the last year before the creation of the Science and Technology Research Council (STFC). The report demonstrated that around 25% of research income related to PPARC astronomy funding.

For groups in 11 institutions, more than 40% of their total research funding related to astronomy, with a further two groups on 38% and 39% respectively. Of the 9 smaller groups with less than £2.5m of EPSRC and PPARC funding, 4 received more than 40% of their funding from astronomy projects and a fifth group received 38% through this route.

Overall the RAS report concluded that around 30% of UK physics departments are strongly dependent on astronomy research funding. Establishing undergraduate degrees and a research base in this area has allowed a number of universities to maintain and bring the opportunity to study physics to areas of the country where it might otherwise not exist.

Leveraging: resources acquired on non-STFC facilities by astronomy research groups

Research groups have been very successful in leveraging resources on non-STFC facilities. RAS fellows have highlighted a number of examples in this area that are set out below. In the case of some disciplines (e.g. solar-terrestrial physics or STP) researchers were keen to stress that the UK is part of a data gathering network – if British facilities close it is to the detriment of researchers in other nations as well as our own.

- UK astronomers routinely acquire time on the NASA / ESA Hubble Space Telescope
- In exchange for software development, Liverpool John Moores University (LivJMU) astrophysics group obtained 50 hours per year of telescope time on the Las Cumbres Observatory Global Telescope Network. The group have received time on the Keck Telescope (run by a private foundation and on Hawaii), Subaru (a Japanese telescope

on Hawaii) and the NASA Spitzer Space Telescope. The LivJMU group also obtained EPSRC funding for a 'Computational Markets' project.

- The Astrophysics group at Imperial College was awarded 9 observing programmes with a total of more than 4m seconds of time on the orbiting NASA Chandra X-ray observatory. Two of these were in the top three largest allocations in the history of the satellite.
- Scientists at the Institute of Astronomy, Cambridge have been awarded considerable blocks of time on NASA's Chandra and Spitzer Observatories.
- In collaboration with the Catholic University of Leuven in Belgium, University of Nottingham astronomers obtained time on the 1.9m telescope at the South African Astronomical Observatory (SAAO) in 2005 and 2007. The same collaboration yielded time on the NASA Spitzer Space Telescope, the Flemish Mercator telescope on La Palma, the Swiss Euler telescope in Chile and two other SAAO instruments.
- Lancaster University physicists in the Department of Communications Systems use US facilities including the HAARP ionospheric heater and the phased-array AMISR radar in Alaska. The group head also has an invitation to use the Arecibo radar and ionospheric heater in 2009. The same team have access to the THEMIS satellites and ground-based instruments (a NASA-led satellite and ground-based study of magnetospheric substorms) and its associated auroral imagers, the Los Alamos National Laboratory geosynchronous satellites, the NASA GOES geosynchronous satellite, the NASA Advanced Composition Explorer (ACE), the NASA WIND satellite, the US Air Force DMSP satellites, ground magnetometers (IMAGE, Greenland, SUPERMAG, ULTIMA, CHARISMA), SuperDARN radars, the Geotail mission and the Japanese Space Agency (JAXA) AARDDVARK very low frequency receivers.
- Sheffield University Astrophysics Group acquired 99 hours of time on the NASA Spitzer Space Telescope.
- A Rutherford Appleton Laboratory (RAL) scientist highlighted a key resource to be the open international exchange of data in STP established in the International Geophysical Year in 1957. This is endorsed by UK agencies including the MOD. It applies to ground-based STP facilities including magnetometer networks, magnetic indices based on those networks, the global solar monitoring network, the global ionosonde network, the global riometer network, the global neutron monitoring network, the SuperDARN network of ionospheric radars and all-sky camera networks in auroral zones. RAL (and other UK) scientists have access to space-based facilities such as Cluster (ESA), Double Star (China / ESA), SOHO (ESA / NASA) and STEREO (ESA / NASA). Access is given to data from non-UK missions including ACE, WIND, POLAR and THEMIS (all NASA), GEOTAIL (JAXA), the GOES and POES missions (NOAA – US) and the US Department of Defence DMSP.
- University of Wales, Aberystwyth, researchers have access to the Chandrayaan (India) and Selene (JAXA) lunar missions, the Japanese STELab data sets and the LOFAR network.

- University of Southampton astronomy researchers are regularly awarded time on NASA missions including Galex (50 kseconds), RXTE (5-10% of available time per annum) and Chandra (several hundred kseconds). They estimate the RXTE time alone to be worth $1m (£509k) per annum. The group has also been awarded significant time (a few nights per annum) on ground-based facilities including the Canada-France-Hawaii Telescope, Subaru, Keck, Palomar (in the US), Cerro Telolo Inter-American Observatory (CTIO) and hundreds of hours on non-UK radio observatories including ATCA, the Westerbork Synthesis Radio Telescope (WSRT), the Very Large Array (VLA) and the Giant Magellan Telescope (GMT). Southampton is the lead institution in the LOFAR-UK consortium which gives it access to the main LOFAR array and is heavily involved in the ESA INTEGRAL gamma-ray mission.
- Solar physicists at the University of Glasgow have significant involvement in the NASA-led RHESSI mission

Astronomy groups with significant funding from sources other than STFC (previously PPARC)

Academics in universities and research establishments drew the attention of the RAS to a range of funding agencies outside of STFC. These encompass the EU framework programmes, charities such as the Leverhulme Trust and Kavli Foundation and the US, Chinese and Indian governments. In one case (RAL) the respondent discussed funding that supported the investigation of a potential market for services accruing from STP research. However, the same respondent expressed concern that STFC is not considering medium- to long-term economic impact of this type when assessing projects and priorities.

- The Institute of Astronomy, University of Cambridge has received significant funding from the Sackler Foundation (for a lecture theatre and instrumentation programme), from N. Corfield (for the Corfield Wing of the Hoyle Building) and from the Kavli Foundation (for the Kavli Institute for Cosmology). The Institute has also joined the Sloan Digital Sky Survey Project.
- LivJMU astrophysics group received EPSRC funding for a 'Computational Markets' projection equivalent to the level of a standard PDRA grant.
- Sheffield University received funding for a Royal Society University Research Fellowship, the Leverhulme Trust and EU funded postdocs (the latter relates to OPTICON Framework 6 funding) and RCUK funded a fellowship.
- The University of Lancaster Communication Systems Department received funding from EPSRC, the EU, China and India.
- RAL was funded by ESA to carry out a cost-benefit analysis on the potential European market for space weather services, carried out by the UK company SEA. MOD funding of £100k operates the ionosonde service for 2007/8, NERC provides £5k per annum for involvement in the GEOSPACE continuum, CCLRC provide £50k for work on mini-magnetospheres, ESA provided €140k (£112k) for a space weather

nanosat study, the EU funds the operation of Cluster via FP6 (£250k per annum) and leadership of data archiving (£50k per annum).

- University of Wales, Aberystwyth researchers participate in the EU funded planetary science network Europlanet.
- Southampton University School of Physics and Astronomy anticipates receiving several million pounds of HEFCE funding as part of an initiative to secure Physics in south-eastern universities. The astronomy group will use its share to support the low-frequency radio observatory LOFAR and create a permanent radio astronomy position, as well as supporting postgraduate training and a EuroMasters degree programme. The group will also soon benefit from €330k (£263k) via the EU FP7 programme for international training networks, in this case relating to the study of accreting black hole systems.
- Durham University used funding from HEFCE and the Ogden Charitable Trust to build the Ogden Centre for Fundamental Physics. A second donation enabled Durham astronomers to join the Pan-STARRS project for detecting asteroids, comets and variable stars.
- Glasgow University received part of a €3.4m (£2.7m) award from the EU for the SOLAIRE grant network, part of a £60k EPSRC award for plasma research, a £130k grant from the Leverhulme Trust for cosmology research, £15k for work relating to the Square Kilometre Array, £75k from the European Gravitational Observatory for work on gravitational wave detectors, £136k from EU FP6 for the same, £1.2m from the Scottish Funding Council for a materials characterisation laboratory, £300k from EU FP7 for a design study for the Einstein Telescope and is part of a $165k (£83k) bid to the US NSF with Cornell University, the University of Massachusetts and the University of Georgia
- The North West Development Agency provided £2.5m to the University of Manchester as a contribution to the £8m capital cost of e-MERLIN at Jodrell Bank radio observatory.

Funding for consortia spanning Physics and non-Physics departments

There a number of examples of work in this area which connect astronomy researchers to those in other disciplines. In their responses to the RAS, researchers were particularly keen to demonstrate the symbiosis between different areas and how an unintended consequence of lower support for astronomy research could be the impact on other research areas. For example, the astrophysics group at St Andrews has a close link with mathematics researchers and warns that both would be undermined if core astronomy funding is diminished.

- NERC and the US Air Force gave around £70k per annum to fund a group in Leeds to investigate metallic layers formed in the upper terrestrial atmosphere resulting from meteors.

- At the University of Wales, Aberystwyth, researchers received Welsh Assembly funding for the Centre for Advanced Materials and Devices (with Bangor and covering Physics, Informatics and Chemistry). HEFCW funded research into planetary robotics.
- Glasgow University astrophysics group works with Liverpool University engineering department on an EPRSC-funded non-equilibrium plasma network
- St Andrews University researchers drew attention to the link between Applied Mathematics Departments and theoretical astrophysics groups, with key examples at St Andrews itself, Glasgow, Cambridge, Exeter, Leeds, Dundee and Sheffield. St Andrews is part of the SOLAIRE consortia funded by an EU grant covering 8-10 applied maths and physics departments across Europe.

International Comparisons

Our international evidence concentrates on two areas: funding and productivity. In both cases it is clear that the UK is a strong performer, with basic research in astronomy and space science that offers better value for money than the majority of our competitors and a prolific output rate.

Comparative International Investment

Woltjer (2006) studied the comparative investment by European states in research in astronomy and space science. In 2003 the UK invested €210m (£167m), which as a proportion of GDP at that time was significantly behind the expenditure of Italy and France and roughly level with Germany. The cost per astronomical researcher was significantly lower (€162k or £129k) than the other major states (the highest value was in Denmark at €293k (£233k), with France at €240k (£191k), Italy at €214k (£170k) and Germany at €211k or £168k).

For comparison, in response to a parliamentary question tabled by MP and RAS fellow David Heathcote-Amory in May 2008, the Minister for Science gave a total of £256m (€322m) for the provisional budget for astronomy and space science research for 2008 (Written Answers TheyWorkForYou.com). This reflects recent and welcome budget growth, but does not take into account the impact of inflation and the incorporation of Full Economic Costing (FEC).

As a member of the European Space Agency (ESA), the UK makes a mandatory and optional contribution to its programmes. BNSC report that in 2008 this amounts to a mandatory contribution of €107.01m (£85.27m) with investment in optional programmes of €157.89m (£125.77m). As a proportion of GDP, this total also compares unfavourably with other member states (UK contributions are half those made by France and about 60% of the level of investment made by Germany and Italy). (Albone & Payne, 2008)

This echoes the concerns expressed by MPs in their 2007 report on space policy where they made the same comparison using 2005 data. (House of Commons Select Committee on Science and Technology, 2007).

Comparative research productivity and efficiency

UK astronomers and space scientists are very productive by world standards. According to In-Cites, between 1995 and 2005 researchers in England and Scotland published 15218 papers in this research area and these received 231572 citations (2005).

On the basis of these data, UK astronomers and space scientists published more papers and were cited more frequently than any other nation in Europe. Worldwide they are second only to their counterparts in the US.

This level of activity was delivered despite somewhat lower investment. Woltjer's study measured the expenditure per page published and demonstrated that the UK has one of the lowest research costs in Europe, at around €26k (£21k) per published page, compared with €60k (£48k) for France, €53k (£42k) for Germany and €49k (£39k) for Italy.

Looking at page publication rates, the UK also performed very strongly. In 2002, on a normalised basis, UK academics published more than 8000 pages in peer-reviewed astronomy journals, more than any other European country and far ahead of the 5500 published by their second-placed German counterparts.

The UK is a very attractive environment for astronomy and space science research, drawing in talented individuals from around the world. However this position may be threatened if the available funding deteriorates, both through a contraction of resources and through damage to our international reputation. The House of Commons Innovation, Universities, Science and Skills Committee report on the Science Budget Allocations identified both of these risks, supported by international correspondence from a number of research establishments (2008).

Economic impact

In our submission, the Society has considered the economic impact of astronomy, space science and geophysics, ranging from direct investment in the private sector resulting from participation in international collaborations to often innovative spinout companies.

Much of this evidence is necessarily qualitative, but none the less gives an indication of the range of commercial enterprises that are a direct result of initial investment in astronomy and space science research and education.

Spin-out companies associated with astronomy and space science groups

RAS fellows provided a number of examples of spinout companies and associated commercial work that stems from astronomy and space science:

- At Cambridge University, Metropolis Data Consultants specialise in image processing and inference, AstroCam work on cameras and instruments for life and physical sciences, Digital Healthcare develop software and imaging hardware for diabetic retinopathy and general ophthalmology and ArCom develop single board computers and control electronics.
- Imperial College London has the spin-out company Optical Surfaces Ltd.
- University College London has the spin-out company OpTIC Technium which specialises in precision mirrors
- Liverpool John Moores University owns a subsidiary company, Telescope Technologies Limited, which has won contracts from around the world and is a rare (possibly unique) example of a firm making robotic telescopes on a production line
- Observatory Sciences Limited is a small company set up following the closure of the Royal Greenwich Observatory in 1998. They employ 6 staff and have a turnover of around £300k, being engaged entirely in work relating to astronomy and particle accelerators.
- A PhD solar physics graduate from St Andrews University set up and manages Fluid Gravity Engineering Ltd, a scientific consultancy that hires many other PhD students on completion of their courses. The company is the major UK modeller of magnetohydrodynamic simulations and their customers include defence contractors and oil and gas companies.
- See3D is based in Aberystwyth and has strong expertise in 3D visualisation. The company uses code developed for visualisation of data from the NASA STEREO mission but has now successfully tendered for commercial contracts.
- The Physics and Astronomy group at Southampton University led to the spin-out company Symetrica which commercialises high-performance gamma-ray imaging hardware. The company has extended its operation to the USA and in 2006 (in

partnership with Smiths Detectors) won a $222m (£113m) contract for homeland security. Symetrica now funds two Southampton graduate students and participates in joint technology contracts with departmental staff.

- At Cardiff University, the spin-out company QMC instruments markets terahertz imaging technology developed for infrared and sub-mm imaging in astronomy. The company employs five staff and has a turnover of more than £1m. The same group also works with a US company to develop high-efficiency laser diodes.
- Knowledge exchange activity at Lancaster University is diverse. The space plasma environment and radio science group work with the US company ASTi on plane communication and aircraft engine noise cancellation. The group work on another project with a small business, HW Communications and are collaborating with the US Air Force Research Laboratory on radiation belt remediation.
- At Leicester University, three spin-out companies are associated with the Space Research Centre. BioAstral is using a £125k OSI grant to undertake research into Superconducting Tunnel Junction applications in life sciences, Gamma Technologies Ltd is forming to develop a miniature gamma ray camera also with a life sciences application through a grant from Lachesis of £250k and Spectral ID could form to pursue anti-counterfeit technology through a £108k Follow on Fund grant from STFC.
- UK universities and research establishments are key partners in the Square Kilometre Array (SKA), the ultra-sensitive radio telescope involving many nations and due to be completed in 2020. Contracts to deliver aspects of this project have been let to Cambridge Consultants (DSP look ahead study), BAE (phased array antenna element study), Roke Manor (phased array architecture study), EEP (supply of an EM-tight container to house high-speed digital hardware), RFMOD (supply of innovative packaging for semiconductor devices) and Selex/Galileo (design validation and testing of high-speed ADC). Future contracts are likely with e2v Technologies (high-speed low-power ADC) and INEX (University of Newcastle – enabling production readiness for advanced semiconductor devices).

Direct return from international collaborations

Direct investment in international projects such as the European Space Agency (ESA) and European Southern Observatory (ESO) yields a return to companies in the UK. In the case of ESA, this return is specified via the 'juste retour' rule that apportions the award of contracts to member states in proportion to their investment in the Agency.

Since 2000, UK companies have received €1.2bn (£960m) in contracts related to ESA with a return of €198m (£157m) on Earth Observation science investment and €285m (£227m) on scientific missions (European Space Agency Industrial Policy Committee, Geographical Distribution of Contracts, 2008).

There is no equivalent 'juste retour' rule for investment in ESO. However the most recent STFC delivery plan gives a value of €2.7m (£2.2m) for contracts related to ESO awarded to UK companies. (STFC Delivery Plan, 2007)

Economic impact from PhD graduates

In 2003 PPARC published a longitudinal study of PhD students, tracking the progress of those whose awards finished around 1988 and who had studied astrophysics or particle physics). This study made contact with 67 former students from an original cohort of 100 first studied in 1995. (DTZPiedaConsulting, 2003)

The majority of those completing the survey (75%) were still employed in scientific research, in the university, private and government sectors. 57% of the cohort earned more than the average professional worker in the UK, implying a high tax return with great added economic value over their careers.

The evidence at undergraduate level is equally convincing. In 2005 the Institute of Physics and Royal Society of Chemistry commissioned a study of the lifetime earnings of graduates across a range of subject areas. They found that physics graduates earned an additional lifetime earnings benefit of between £185k and £190k. Even after the higher costs of training physics students is considered, the career lifetime tax return to the Exchequer amounted to £134k. (Institute of Physics and Royal Society of Chemistry, 2005)

Wider impact on private industry

As well as the examples of spin-out companies described above, there is a significant wider space industry. The British National Space Centre (BNSC) estimated it to have a turnover of £4.8bn in 2004/2005 with around 16200 employees, mostly in London and the South East and with smaller numbers based in the South West and Yorkshire. (Spencer & Hulbert, 2006)

Spencer and Hulbert refer to an Oxford Economic Forecasting estimate that the industry supports 70000 jobs and contributes around £7bn per annum to domestic GDP. On these figures, the sector has one of the highest productivities in the UK. With 57% of employees qualified to at least first degree level, the industry also has one of the highest employee skill levels.

One of the largest employers is Astrium Ltd, with 2500 employees, principally at sites in Stevenage and Portsmouth. The company concentrates on engineering and develops space-based infrastructure and services for clients in the commercial and public sector, including Earth observation and meteorology as well as scientific missions for astronomy, planetary science and STP.

Astrium recruits a large number of physics specialists with qualifications from first degrees to doctorates. The company highlighted six members of staff who have degrees in physics and astronomy from the University of Leicester alone and who are in roles from mission studies to project management and media and communications.

Astrium believes that it derives considerable benefit from UK-trained graduates and PhDs with backgrounds in basic research in astronomy and space science and the company directly and indirectly utilises specialist skills developed at postgraduate and postdoctoral level. For example, one former cosmic ray physicist is now a technical project manager and a former radio astronomer is now a business development manager.

References

Albone, D., & Payne, A. (2008). BNSC data, private communication.

Barstow, M. (2005). *Bringing Space into School Science.* BNSC Partnership, EADS Astrium, PPARC, Yorkshire Forward.

Blackwood, A. (2006). *Scottish Space School.* Careers Scotland.

DTZPiedaConsulting. (2003, July). *A Fifteen Year Longitudinal Career Path Study of PPARC PhD Students.* Retrieved from http://www.so.stfc.ac.uk/publications/PiedaOldCohort.pdf

(2008). *European Space Agency Industrial Policy Committee, Geographical Distribution of Contracts.* ESA.

House of Commons Select Committee on Science and Technology. (2007, July 17). *2007: A Space Policy.* Retrieved from House of Commons Select Committee on Science and Technology: http://www.parliament.the-stationery-office.co.uk/pa/cm200607/cmselect/cmsctech/66/66i.pdf

House of Commons Universities, Innovation, Science and Skills Select Committee. (2008, April 30). Retrieved from http://www.publications.parliament.uk/pa/cm200708/cmselect/cmdius/215/215.pdf

Institute of Physics and Royal Society of Chemistry. (2005, January). *The economic benefits of higher education qualifications.* Retrieved from Institute of Physics: http://www.iop.org/activity/policy/Publications/file_4149.pdf

Jarvis, T., & Pell, A. (2002). *Journal of Research in Science Teaching* , 979.

Jarvis, T., & Pell, A. (2005). *Journal of Research in Science Teaching* , 53.

Massey, R. M. (2008). *RAS Survey of Taught Astronomy, in preparation.*

Osborne, J. F., & Collins, S. (2000). *Pupils' views of the School Science Curriculum.* King's College London.

Spencer, P., & Hulbert, G. (2006). *The Education and Skills Case for Space.* BNSC Partnership.

STFC Delivery Plan. (2007, December 11). Retrieved from http://www.stfc.ac.uk/resources/pdf/delpan07.pdf

The 20 Most-Cited Countries in Space Science, 1995-June 30, 2005. (2005, October). Retrieved from in-cites: http://www.in-cites.com/countries/top20spa.html

Williams, I. (2008). Private communication.

Woltjer, L. (2006). *Europe's Quest for the Universe.* Les Ulix Cedex, France: EDP Sciences.

Written Answers TheyWorkForYou.com. (2008, May 14). Retrieved from http://www.theyworkforyou.com/wrans/?id=2008-05-14a.205313.h&s=david+heathcoat-amory#g205313.q0