STFC Balance of Programmes Exercise 2016

Input from the Solar System Advisory Panel (SSAP)

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Q1. Please provide an update on any changes to your most recent science roadmap.

The STFC Solar System Advisory Panel (SSAP) roadmap was updated in July 2015 and **no significant changes are required to the science questions that represent the scientific priorities for the UK Solar System community**. Minor changes (on pages 30 and 31) are:

- "Microgravity facilities" (described under the heading ELIPS "European programme for LIfe and Physical sciences and applications utilising the international space Station" in the current roadmap version) – which includes experiments on the International Space Station – and space environments, e.g., parabolic flights, and drop towers should be included under "current facilities" to answer question in the "Planets and Life" section.
- The Solar Wind Magnetosphere Ionosphere Link Explorer (SMILE) mission should be included in "Solar Variability and its Impact on Us".

It is important for STFC and the Balance of Programmes panel to recognise that the SSAP roadmap is composed of science questions in three themes: "Solar Variability and its Impact on Us", "Planets and Life", and "Universal Processes". As stated in the SSAP roadmap "*Because the scope of this theme is so broad, in terms of application of the different processes to specific situations or environments, it is impractical to list areas of UK excellence, or missions or facilities that are key to answering the questions."* The absence of a traceability matrix between the science questions in the universal processes theme and missions/facilities should not be misinterpreted as lacking in importance or priority. Addressing 'fundamental' physical problems in Solar System physics is a UK strength. The missions/facilities with clear traceability to the first two themes all provide capacity to address universal processes.

Our roadmap highlights a variety of mission concepts that have been proposed to the European Space Agency (ESA) and these might be seen as emerging opportunities in the next five years in addition to the space-based and ground-based facilities already mentioned in the SSAP Roadmap (2015). **Facilities/missions that may require new involvement/support from STFC in the next five years include**:

- ESA M4 missions currently under study by ESA which have UK team member/instrument team involvement and are relevant for Solar System science: Atmosphere Remote-Sensing Infrared Exoplanet Large-survey (Ariel), and the Turbulence Heating ObserveR (Thor). These are currently scheduled to launch in 2025.
- Proposals submitted to ESA's M5 mission call and ESA's New Scientific Ideas call may also require new involvements/support from STFC and include orbital missions to Venus, the outer planets (Uranus or Neptune), solar observatories, Solar

System small bodies, landers to the Moon, and hard lander systems (penetrators) for a variety of Solar System bodies (e.g., Europa).

- UKSA, in partnership with ESA and other space agencies, is also involved in technology demonstration missions for sample return. The targets for such samples include the Moon, moons of Mars (Phobos and Deimos), Mars itself, and comets. This emerging opportunity will also potentially require new support in terms of flight instrument development, geological landing site selection, and in ground-based laboratory support for developing techniques to analyse extraterrestrial materials.
- Other emerging mission/facility opportunities include Luna 27 (PROSPECT package – ESA contract), Chandrayaan-2 (bilateral with India), AIDA/AIM, the European Solar Telescope (EST), which has been adopted onto the ESFRI Roadmap and the results of NASA SMEX, Discovery and New Frontiers mission calls.
- Sample curation is identified in our roadmap. The UK is now a world leader in extraterrestrial and potentially biohazadous sample curation expertise with extensive participation in the EU Horizon 2020 project 'European Curation of Astromaterials Returned from Exploration of Space' (EURO-CARES). Participating UK bodies include The Natural History Museum, Thales Alenia Space UK, The Open University, Public Health England, the University of Leicester.
- An implication of the Modern Transport Bill is that a UK spaceport could potentially be operating in the next five years enabling low-cost access to space. This capability may drive low cost-space exploration offering new opportunities for STFC-relevant R&D and exploitation.
- Some of the scientific questions posed by this community require a long temporal baseline of observations in order to make progress and so the field benefits from access to historical data. Much of the historical data is not in an electronic form. Following progress made by other international funding agencies a modest funding line to digitise and curate these historical data would be of benefit.

As space mission support is in the remit of UKSA we do not comment on what missions may be appropriate for a withdrawal of support from STFC. SSAP makes absolute its support for the funding of scientifically excellent and competitive projects that use these facilities and are ranked highly via peer review.

Q2. The last programmatic review advocated broadening the programme whilst maintaining the most appropriate balance between R&D, construction, operation and scientific exploitation. Do you believe the current programme activities have achieved this? Please highlight any particular successes (or failures).

Overall the view of the community and of SSAP is that the programme as generally reasonably balanced. However, some community feedback views the programme as being too broad, and some as too narrow. To some extent the breadth of the field is dictated by ESA who ultimately decide what space missions to select for the M, L and S class mission programmes. There is also concern that the driving of the science programme by the technology programme forces breadth. A clear example is the ESA Aurora programme which has currently pushed some planetary science work, expertise and training into a very focused research area. This is not necessarily a positive or negative outcome, however it is an example where the breadth of the programme is forced by factors outside of STFC control.

There are three key areas where some parts of the community have felt that the balance between R&D, construction, operation and scientific exploitation has not been appropriate. These are in funding for exploitation, funding for novel instrument development, and provision for High Performance Computing (HPC). We comment on the latter in our response to Q6.

In the case of exploitation there is a potential contrast in the community between groups involved in hardware and instrumentation development, and those that are focused on theory/exploitation. For example, one respondent wrote "*Currently it is very difficult to do scientific exploitation of missions which are no longer operational. It provides a strong limitation to scientific return, while sometimes a lot of money has been invested in hardware and significantly less extra support is needed for further data exploitation and very high scientific return."* and another wrote *"I sometimes wonder if we have fully exploited some of the satellite missions in which we are involved.*". As a counter-point to this, another respondent wrote "*Within 3 years of end of mission, we could phase out scientific exploitation."* A minority of respondents to our community consultation view that there is a perceived bias towards exploiting new and current facilities rather than proposals judged on the quality of the scientific case – even if this involves the analysis of historical data. Although it is the understanding of SSAP that this is not necessarily the case on the ground within AGP. Whilst SSAP does not have sufficient factual evidence in order to made a recommendation on this point we do make the following remarks:

- The programme must be balanced to allow both types of activity to proceed.
- Proper allocation of funds should be made to support facilities in which the UK has made major hardware investments and presents UK leadership.
- We urge ongoing vigilance in this area to ensure an appropriate balance is struck.

In the case of R&D it is generally acknowledged that in the past communication between STFC and UKSA, and to the community, has been inadequate in terms of what TRL ranges will be supported by which funding body. **This has adversely affected the UK community, its world standing and ability to compete internationally**. This has prevented the UK from pursuing novel instrument development at a pace commensurate with our international competitors. Although the communication is now in principle clear, with TRL 1-3 within STFC's remit, there are potential ongoing issues that are centred on reviewers and review panels not recognising this official position on remit, and anecdotal remarks that review committees possibly prioritise data analysis over instrumentation. In this context, rolling grants were much better at mitigating these issues and balancing the programme as a proposal was made for a programme of activities where the case for instrumentation development could be clearly made in the context of the associated science within the programme. Potential routes to resolve these issues include additional funds to PPRP/PRD, or the establishment of instrumentation sub-panels on AGP. The latter would also aid in the natural business of AGP.

Particular successes of the current programme include Cassini-Huygens (for example, five of the top 10 discoveries made by Cassini-Huygens have had significant involvement and leadership from UK scientists), Rosetta (including the first landing on a comet and observing comet activity increase towards perihelion), and involvement in other high profile international missions (e.g., Mars Science Laboratory/Curiosity), UK solar physics (in particular spectroscopy and theory via HPC), cosmochemistry and meteorite/planetary materials science relative to the size of the UK community, and funding of PhD studentships.

Failures of the current programme are essentially systemic and include:

- A lack of investment in support for early career Solar System scientists.
- Lack of transparency in community understanding of the dual UKSA and STFC roles – although SSAP acknowledge that this situation is improving.
- Mismatch in the funding priorities and drivers for STFC and UKSA, and the multiple reviews arranged by each funding body are continuing examples of the ongoing difficulties in the dual key approach.
- The division of research on the Earth's space environment between ground-based facilities/research supported by NERC and space-based facilities/research by STFC has adversely affected the field.

Community feedback over a range of points also exposed a general belief that the expertise and breadth of coverage on various panels, including the fellowships panel and AGP, was inadequate. This not only applies to coverage of scientific disciplines, but also to panel members who have a more detailed background in simulations, laboratory work, and instrument development. It is the view of SSAP that the onus should be on the community to drive suitable nominations for panel membership in order to ensure that panels are appropriately balanced and have sufficient expertise. However, to ease community concerns some interaction between panel chairs and the advisory structure might be appropriate to ensure balance. This may take the form of the advisory structure commenting on new appointments to fellowship panels and AGP.

Q3. It was recognised at the time of the last programmatic review that should a flat-cash funding environment continue the balance of programmes should be re-examined to ensure sustainability. What steps should be taken to obtain the appropriate balance of adequately supported projects in your field? How can the field be scientifically sustainable in a continuing flat cash/no inflation environment over the next 5 years? At a strategic level, broadly speaking what would be the impact of reduced/increased funding (+/- 5%)?

Within the field there is a natural split between groups that are involved in instrument build, theory/simulations/HPC, and data exploitation. This is clearly revealed in our community survey with some input suggesting, e.g., '*Exploitation funding is a must*' and '*Exploration funding should be maximised*' Vs. '*I do not see any value in maximising exploitation unless the UK wants to become just a consumer of data … to maintain strategic oversight, technical know-how and science and mission leadership there needs to be a balance between project spending and exploitation*' and '*Exploitation is important, but the new science is often driven by new observations*'. Therefore there must be an appropriate balance between funding for i) exploitation of projects in which the UK is leading and providing hardware; ii) exploitation of data from international projects where the UK is not a major player but which help us to address priority science questions; iii) participation in projects and missions, including the funding (via PPRP/PRD and UKSA) to develop novel instrumentation; and iv) adequate support for theory, supporting laboratory work and simulations/HPC.

A strategic prioritisation process will be carried out in 2016/2017 by SSAP in order to examine the range of projects in the field and to better inform the appropriate balance of adequately supported projects and activities. We have received a strong steer from the community that this should be done in consultation with UKSA, ESA and the wider Global Exploration Strategy. However, it is a general view that currently the balance is skewed against HPC-based theoretical work, the development of next generation novel instrumentation, and laboratory projects.

One route to sustainability in a continuing flat-cash environment could be to adjust fEC for academics paid on grants via AGP. In our community survey **the overwhelming response was either strongly opposing a removal of fEC for academics** or very cautiously suggesting that such a removal/adjustment may ease a burden and enabling the grants line to support more projects. However, the removal of fEC for academics could lead to a reduction in the amount of teaching 'buy-out' that academics can make and so science output and leadership will suffer. This will affect both the support of oversight of PDRAs funded by AGP and in science carried out by academics. Removal of this fEC will effectively stop research at some teaching-focused universities. Institutions have come to rely on this fEC to support research and so would have an effect on the funding of the UK system. One respondent suggested completely removing fEC as the current levels of 0.1-0.2 FTE were already too low to be meaningful, but another respondent said that the removal of such (already low) levels of support would be disastrous. A small minority of the community strongly endorsed the removal of fEC for academics. A clear argument for this that appeared multiple times was in how different institutions 'reward' fEC. For some institutions fEC translates directly to a workload allocation to research, in other institutions proper workload models are not in place. The effect of this is that at some institutions levels of research income via fEC does not have an effect on the balance of teaching, administration and research and so universities are effectively taking fEC and not providing adequate time for academics to work on projects. More complete auditing and capping of fEC may be a way of supporting a greater number of projects. **However, in the light of the highly contentious topic SSAP strongly urge STFC to act on this advisory panel input in a circumspect fashion.**

It is generally felt that there is an unsustainable lack of opportunities for postdoctoral fellows. In the Solar System area, the Royal Astronomical Society has temporarily supported a small number of postdoctoral fellowships in response to STFC discontinuing the Postdoctoral Fellowship programme. Rebalancing the fellowship programme with small reductions in the number of advanced fellowships and a limit fEC on these fellowships would permit the re-establishment of a junior postdoctoral fellowship scheme.

SSAP obtained a range of comments on the breadth of the programme. There was a general feeling that in order for the field to be sustainable in a future flat-cash environment then some contraction of the programme would be necessary. However, sufficient breadth is necessary to ensure that the field does not concentrate in a few areas that may not necessarily be productive in the next ten years. In this case it may be necessary for STFC and UKSA to jointly decide not to participate in some ESA missions in order to adequately support other areas of the programme. However, there is also a need for SSAP and STFC to drive the ESA programme via UKSA. It is important that any contraction of the programme does not disproportionately affect the smaller research groups.

At an overall strategic level the effect of a 5% cut will result in very large negative effects on the programme, including the closure of groups and a weakening of the UK's international impact in science. However, the exact effect depends on where these cuts would be applied. If applied to facilities/missions then this would result in a contraction in breadth of the programme and a loss of international leadership. If facilities and missions are protected then these cuts will be absorbed from studentships, fellowships and the grants line. This would be devastating for universities and research would retreat from universities into large facilities/laboratories. Many respondents felt that funding was already at, if not below a critical sustainable level. **In the event of a 5% overall cut, the panel concludes that highest priority should be given to protecting the grants line of funding.**

It is also important to recognise that **a -5% change cannot be considered in isolation from the effects of Brexit**, the effects of which are already having a negative effect on the community. Particular factors of concern are the fall in the value of the pound, difficulties in attracting and retaining international staff, uncertainty regarding future participation in European research networks, and uncertainties in likely new rules regarding the movement of goods.

Uplift by +5% would enable a range of activities, including improvements to the fellowship programme and grants line. This would enable us to keep the best talent in the UK and attract new talent.

Q4. In addition to supporting our science we recognise that the science programme results in the development of enabling technology that builds capability for UK.

The UK has strengths in a range of areas associated with detection technology and is a world-leader in mass spectrometers, magnetometers, in situ plasma detectors, X-ray diffraction, seismometers and imagers/spectrometers. These also benefit from world-leading expertise in miniaturisation technology. The benefits of these technologies include applications in health care, defense, Earth observation, operational Space Weather, and mining. The UK is also a world-leader in cryogenics for space missions, planetary surface hard-landers 'penetrators' (involving collaborations between academia and Qinetic), and is the leader in Europe for space nuclear power and heating sources (in collaboration with ESA, the space industry, and the National Nuclear Laboratory).

In spite of this leadership, the general community feeling is that STFC is not providing sufficient funding to enable the development of critical technologies for the future health of the field. One respondent anecdotally suggested that AGP is now tending not to fund blue skies space instrument research in favour of exploitation funding for data from new missions. Separate calls for key technology development would allow a panel to be more tuned to technological needs. Some joined-up thinking between BEIS and STFC might promote technology development with industrial applications that would keep the field internationally competitive whilst also aiding economic return. An example of this is synthetic aperture radar which is a key Earth Observation technology and is also important in space exploration (e.g., Venus). Another is THz detectors that are relevant for applications in security and telecommunications. Collaboration across NERC, STFC and

EPSRC on fundamental technology development would also better support the field in developing novel low TRL technology.

Most of our instrument/flight hardware technology development is tied in some way to the ESA programme. The timelines of these programmes are long and biased against lower-TRL technologies. This offers limited scope for novel instrument development and limits the participation of SMEs in the space sector. Bilateral opportunities, or a national balloon or rocket programme, would provide a better development environment for enabling technology that builds UK capability.

Technology also extends to numerical models. Whilst many models can produce scientific results for years without major upgrades, eventually significant new developments are required to keep pace with science and our international competitors. It is critical that such major model developments are adequately supported to maintain UK leadership and competitiveness in a range of fields. It is extremely important to recognise the impact of a lack of funding for the development of numerical models, the development of junior scientists trained in these techniques, and the lack of human resources and programming support in these areas. To improve the development of these critical technologies STFC should consider the development of numerical models in a similar way to the development of new telescopes, space instrumentation, or new detectors for particle physics. The work requires developing the basic formalism, considering numerical aspects, algorithm development, implementation, testing (on smaller-scale facilities enable capabilities to be checked, hence the requirement for a range of HPC facilities), and documentation. These developments take time, often longer than a three year consolidated grant period, and during this period publication rates will drop. This must be recognised by grants panels. A possible way forward is to establish a) a clear policy for grants to support software development to add new physics and to rewrite code to benefit from new hardware developments; b) grants lines should have simple formulae to fund HPC storage; c) PPRP should accept proposals for software development. These policies should enable proposals to request full funding for dedicated support programmers in addition to contributions for system administrators. These roles are separate, but both are essential.

Q5. Our science programmes depend on a pipeline of skilled people. Do you feel the current balance that exists for students, PDRAs, academic staff, technicians, engineers, software engineers etc. is roughly correct in your field? Are there sufficient skills, experience and leadership for the current and projected future programme or are there areas where these are lacking?

General remarks from the community suggest that the balance is approximately right between students, PDRAs, academics, and technical staff. Although the years of flat-cash funding have deeply affected the grants line and the numbers of PDRAs. There is a general consensus that the period between PhD and the ability to apply for an advanced fellowship (Royal Society URF or STFC ERF for example) is somewhat volatile for junior scientists. Technical support was one clear area where support was lacking and the balance was not positive. This is in both the skills for developing novel instrumentation and for the development of software and new models.

The field is now starting to see a lack of experience and leadership for the development of advanced numerical models; for example Space Weather Operations Centre, newly established at the Met Office, is facing a shortage of candidates with sufficient skills, experience and leadership in space weather forecasting/modelling.

In general terms, Solar System research produces students and postdocs that are highly computer literate with strong data analysis skills. With relevance across a wide range of the public and private sector. Much of the UK theoretical work involves development and running of high performance computer simulations. The skills gained from these tasks are essential in many industries, including finance and the world of 'Big Data'. PhDs with strong computational skills from our field have gone on to work for high-tech SMEs including First Light and Imaging, and Fluid Gravity Engineering Ltd, and AWE. This is of clear benefit to the UK high-tech skills base.

The mission and instrumentation programme in the UK provides highly-skilled engineers. Satellite applications and the UK space sector benefit enormously from this training and the expertise present in UK academic institutions. The space sector is growing strongly and will be contribute to an increasingly large part of the world economy in the coming years. The UK needs to invest in the area so that there is a sufficient amount of individuals at the forefront of space knowledge and technologies that can innovate in the UK.

Q6. Our science areas are increasingly reliant on mid and high level computing needs (including software development).

Both the current computing resource and foreseen future computing resource needs for Solar System science are inadequate. As our understanding improves, internationally-competitive theoretical work must address increasingly detailed phenomena at a variety of physical scales. This places pressure on national facilities and funding to maintain them at the forefront of computing capability. The key national facility for HPC, DiRAC-2 is chronically oversubscribed by a factor of around two. This should be alleviated in the next five years with the development of DiRAC-3, but this is contingent on central government funding. HPC, and the science it enables, represents excellent value for money. The case for its growth and development must be impressed upon BEIS. As highlighted by the community "Computing shouldn't be an afterthought…".

There are two key issues that affect how the UK is able to translate investment in HPC into internationally-leading science with high impact. The first is the disconnect between funding for PDRA posts and allocation of time on central HPC facilities. A PDRA post to do theoretical work involving HPC may be allocated funding by AGP but then not awarded time on DiRAC. This is exacerbated by the fact that for some projects consolidated grant and HPC allocation cycles may be dramatically out of sync. This is clearly not an efficient management of resource in a highly-constrained funding environment.

The second key issue is in the provision of support for novel and next-generation code development. There are few opportunities to secure funding for the type of large-scale software development that can be crucial for enhancing the scientific return from observations, and for maintaining UK leadership in theory. One example of the is in the development of code to exploit observations to be made by Solar Orbiter in the next 5-10 years, where there is considerable UK leadership. An example of the latter is the development of code for non-local thermodynamic equilibrium (non-LTE) radiative transfer modelling in solar and stellar atmospheres. There is a general lack of recognition of the importance of modern code development by grants panels. It is becoming the standard amongst the leading international peer-reviewed journals that code used in scientific research must be made available alongside any publications. It is essential therefore that both scientists and engineers are schooled in best practice for software development, version control and curation, and that these skills are kept up to date. If there are no mechanisms to support the development of new internationally-competitive models then the UK will not remain internationally competitive. Any support mechanisms must recognise that the development of new models and code is akin to the development of scientific instruments and which often do not generate publications over a grant cycle. There are also issues over inadequate training for the use of national facilities and a lack of provision for software engineers in research groups (not system administrators, but professional software engineers).

A large fraction of the UK Solar System Community is involved in the UKMHD consortium that has a long history of transformative use of UK HPC in addressing some of the most challenging problems in Solar Physics. In the transition from DiRAC-1 to DiRAC-2 the number of awarded core hours changed from 17 million core hours in 2011 (DiRAC-1) to 37 million core hours in 2013 (DiRAC-1 and DiRAC-2), to 7 million core hours (DiRAC-2) in 2016. In addition UKMHD were significant users of PRACE (an EU HPC project) and local EPSRC resources that are no longer funded. The net effect has been that this area of internationally-leading UK science has seen a reduction in HPC resources (measured in core hours) by a factor of ten. Typically, the code used by the UKMHD consortium is not off-the-shelf but is bespoke and has and have been developed over the last decade on remarkably stable systems (in terms of consistent architecture). The transition to DiRAC-2 has meant switching architectures that has required some changes to the codebase and operating procedures (affecting the ability of the field to use allocated core hours) and also workflows that are sub-optimal for the field (possibly also an effect of the highly customised code). UKMHD also had a transition to a peer review model for HPC time allocation that did not include any representation from Solar System science and no change management was involved. However, thankfully this is recognised by the DiRAC leadership and there is now MHD representation on the DiRAC Project Management board. To summarise, not only has the field suffered a dramatic and abrupt reduction in resource, but the transition between resources has not been smooth. SSAP gratefully acknowledge the efforts of the DiRAC leadership in trying to resolve these issues but we urge them to continue their efforts. We also welcome to increase in use of national HPC facilities in other areas of Solar System science.

High Throughput Computing (HTC) will also become more important in the UK in the next 5 years as future mission data returns and processing requirements are expected to scale by a factor of ten compared to now.