STFC Astronomy Advisory Panel

Report to the STFC Balance of Programmes Review (September 2016)

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Overview

This report provides the AAP response to the request from STFC Science Board for answers to a set of questions regarding the balance between different aspects of the STFC programme. The AAP consulted the astronomy community and this information, plus other reports and documents available to the panel, has informed our response. The request for information comes at a challenging time for UK science due to continued financial pressures and the recent vote to leave the European Union, given that the EU constitutes a major funding source for UK astronomers. In constructing our response we have considered the outcome of the most recent programmatic review (2012) modified by events which have occurred since that review. In particular, we have taken into account the most significant changes in scientific priorities, driven by results and by changes in the availability of current and future facilities. Astronomy is a fast moving field of science but also relies on long-term investment in facilities and technology development. Striking the appropriate balance between exploitation, operations and development is therefore crucial to the continued strength of the area. We have also taken account of how UK astronomy fits into an international context. Many of the facilities used by UK astronomers are international in both funding and location. International collaboration can provide some welcome resilience to short-term funding challenges, but can also lock in funding decisions for many years. This can place extreme pressure on the more "flexible" funding areas, and in particular exploitation budgets.

Although this report is for STFC, we have taken due account of both STFC and UK Space Agency (UKSA) activities, as astronomy depends on access to both ground and space facilities. We note the continued debate within the community on the relationship between STFC and UKSA. There are concerns that UKSA is not adequately funding future space science facilities, particularly in terms of contributions to payload provision, reducing the scope of UK leadership (PI roles). The decision making process within UKSA is also rather opaque and there is felt to be inadequate meaningful consultation with the community.

The strongest message which came from the community, and which confirms previous consultations, is the intense pressure felt on exploitation funding. This has been eased somewhat by the success of UK astronomers in winning EU funding (for both exploitation and technology/facility development), but this dual funding stream is now at risk. In particular, we highlight that the number of universities with astronomy groups has grown since the 2012 report, reflecting the strength and depth the UK has in this area within the STFC remit. We also note that the number of applicants on consolidated grants is rising (e.g. comparing the 3-year, 2011-2013 cycle with 2012-16, the rise in applicants is about 15%). This is happening is at a time when exploitation funding levels for astronomy are flat in cash terms. The AGP has provided a modest level of FEC for some applicants who fail to get PDRA funding, but, in the long-term, a rise in applicant numbers combined with a squeeze on alternate funding streams, such as the EU, may cause major harm to exploitation support. This situation can only be sustained if STFC provides additional funding to the astronomy programme.

Astronomy, unlike some other research areas, thrives due to access to facilities covering a range in both scale and sensitivity. Key data can come from not just from the largest international observatories, but also from access to small facilities, including using the latter as feeders for competitive access to the most oversubscribed observatories (e.g. NGTS supplying targets for JWST, JCMT for ALMA). Historically the UK has an outstanding track record in achieving a good balance between larger and smaller facilities, developing some which use off-the-shelf (i.e., cheap) technology while also developing cutting-edge technology which underpins the largest facilities. Technology development not only results in new observational capability but also trains and informs astronomers in the use of facilities which is essential for proper understanding of data. More recently, High Performance Computing (HPC) has become a standard tool not only for theoretical modelling but also for bulk data processing, a requirement which is rapidly growing in importance as data volumes grow. The various facilities then have to be operated in both an efficient and flexible way to allow access to the sky and compute power. The operations budget for one facility cannot be reduced in isolation without taking account of the implications on the use of other facilities.

Finally, we appreciate the growing inter-relationship between electromagnetic and other cosmic messengers, particularly neutrinos and gravitational waves. Both have been detected from distant cosmic sources since the last programmatic review and underline why achieving balance in the programme is so vital.

1. Consultation Process

To inform our response to the questions posed by Science Board we conducted a consultation exercise with the UK astronomy community via an on-line survey during summer 2016. This was advertised via astrocommunity, the RAS and other routes. We greatly appreciate the help of our STFC colleagues in assembling the survey, providing us with the results promptly in a digestible format and in providing other contextual information.

We posed a set of questions which had two main aims: (1) Update the scientific priority areas (and facilities) summarized in the last programmatic review. That review outlined seven high-level science areas, with sub-topics. The community were also asked to provide examples of new areas and/or results and/or facilities that should be taken into account. (2) Provide input to answer the questions posed by Science Board on programme balance, technology, skills and computing. About 200 responses were received and all were taken into account in this report. The responses were anonymized before being provided to the panel (i.e., we were interested in the content not the status of the respondent). We also read previous reports and other documents and surveys. We did not seek white paper or facility input as this report is not part of a programmatic review.

2. Response to Questions

Q1: *Please provide an update on any changes to your most recent science roadmap. Specifically, please ensure that:*

- The scientific priorities of your area are clearly listed, taking into account any recent changes;

- You list activities/projects to cater for potential involvement in new or emerging opportunities;

- In order to enable support for new opportunities and the stated priorities, you identify any areas where the level of support could be reduced.

The 2012 AAP Programmatic Review report listed seven high-level science areas, each with 2-4 sub-themes. Listed in the order they appeared in the report, they are:

- Life in the Universe

- The formation of stars and planets in the Milky Way and other galaxies
- Stellar evolution and stellar populations
- The formation and evolution of galaxies
- The dark ages and first light
- Precision cosmology
- Extreme astrophysics

The community was given the opportunity to rate the seven high-level science areas, each with 2-4 sub-themes, in order of importance. No science area received a low rating. The highest priorities were given to the themes on the processes that govern star formation in our own as well as in other galaxies, and how galaxies form and evolve. In light of the changes to facility funding since the last Programmatic Review, and considering that more changes are in the pipeline, the community was also asked whether within their priority areas, the most important science questions and challenges have changed since the last review. There was a general consensus that the topics listed in the previous programmatic review were still of high importance. However, the community would like to see the following areas more emphasized: 1) gravitational wave follow-up and black hole research; 2) a more explicit emphasis on supernovae and their origins and the origin of dust; 3) time-domain astronomy; 4) the importance of AGNs in several areas of galaxy evolution and formation. It was also emphasized how the results from the recent exoplanet review ought to be taken into consideration. The importance of GAIA and ALMA was reiterated by the majority of the responses.

Examples of some welcome STFC "new starts" include: the Next Generation Transit Facility (NGTS); the High Accuracy Radial Velocity Planet Searcher 3 (HARPS3) at the INT; and the UK joining the Large Synoptic Survey Telescope (LSST) project. These were projects which the community recommended get support and we thank STFC for providing new opportunities at a time of financial pressure. These projects also illustrate the range in scale of projects which can provide world-class science (differing by a factor of several hundred in total cost). New UKSA supported ESA projects are the PLATO exoplanet mission (M3) and the Athena X-ray observatory (L2), with a down-select due for the M4 mission shortly. PLATO and Athena provide strong support for high-priority STFC science areas. We welcome the (albeit very modest) support STFC provides for the science teams on such missions.

We note that the amount of observing time which UK astronomers can access continues to decline as we withdraw funding from observatories (there is no UK guaranteed time at ESO except to instrument teams). This process will, over time, result in less observational experience and have a negative impact on scientific leadership. It is crucial that no further reductions in sky access occur.

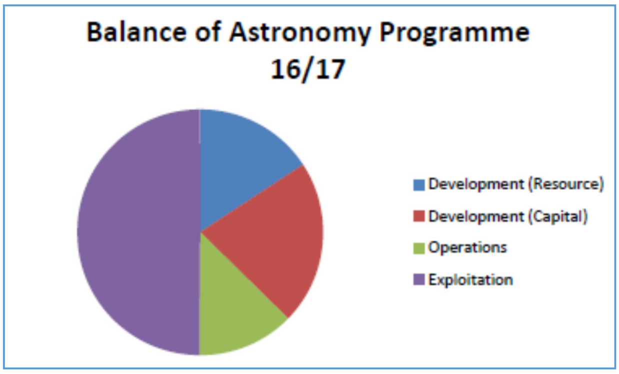
Q2: *The last programmatic review advocated broadening the programme whilst maintaining the most appropriate balance between R&D, construction, operation and scientific exploitation.*

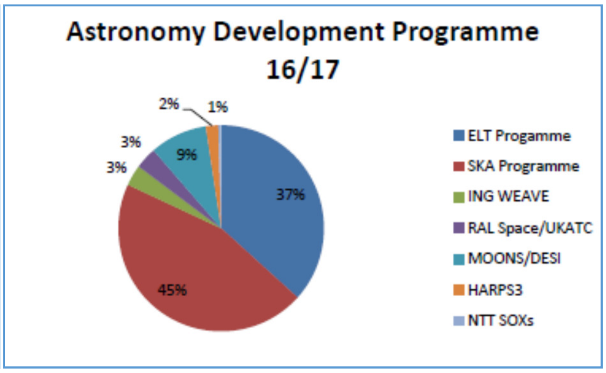
- Do you believe the current programme activities have achieved this?

- Please highlight any particular successes (or failures).

Based on the answers to the community survey, there is broad support for the current balance of activities, a summary of which is shown in the pie charts below along with the current relative spend on development. A sizeable number of respondents (about one third) noted the strain that science exploitation is under and pleaded for ring-fencing the exploitation budget, while about one fifth of the respondents argued for an increase in the exploitation budget even under a flat-cash settlement. Adequate exploitation funding is necessary to ensure that the UK can reap the benefits from the investment that was and is being made to maintain access to world-class facilities. Currently, ERC funding is seen to significantly alleviate the strain on the grants line. Many survey respondents voiced uncertainty over how `Brexit' would affect access to European funding and the role of the UK in setting the European research agenda if the UK were to remain within the ERC framework.

There appears to be very little appetite in the community to increase relative spending for facilities or operations, though the need for continuing R&D was underlined. A sizeable fraction of the replies expressed support for the E-ELT and some voices acknowledged that a *temporary* increase in investment might be needed to ensure timely completion. A similar number of respondents warned that there is currently a danger that expertise will be lost and innovation stifled if support for smaller facilities (e.g., ING, NGTS, LOFAR…) is lost as many of these serve not only as key observing facilities but also as test beds and ensure that the UK is in a leading position to secure contracts when new instruments and facilities are built. This argument does not only apply to hardware: with ROE and CASU, the UK is currently a leader in pipeline processing for large surveys.





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. In the light of this, could you consider the following? (Please note that we recognise that the Advisory Panels do not normally consider financial details of the programme, so the responses must be educated assessments of the situation).*

- 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%)?

In 2012, the AAP produced a report detailing a sustainable and balanced astronomy programme (pp 19-21, AAP PR report, 2012). In response to this question, we have revisited this proposed programme in light of the continuing flat-cash/no-inflation environment, based on both our community responses and on changing scientific opportunities, and have produced the following update to our priority list:

Highest priority:

- *Exploitation grants*. As in our last report, exploitation grants remain amongst our very highest priorities. These grant lines support all of the astronomy science and technology activities in the UK, and continue to be under intense pressure. STFC should also strongly support attempts for the UK to retain access to EU-funded programmes.

- Continued membership of the *European Southern Observatory* (ESO), including access to Paranal, La Silla and ALMA, and future access to the E-ELT. Continued access to and development of ESO facilities is critical across the astronomy science programme.

- Continued investment in *High Performance and High Throughput Computing (HPC and HTC)*. HPC/HTC has become increasingly important over the past decade, from theoretical, simulation, modelling and observational data processing/storage perspectives (see Q6).

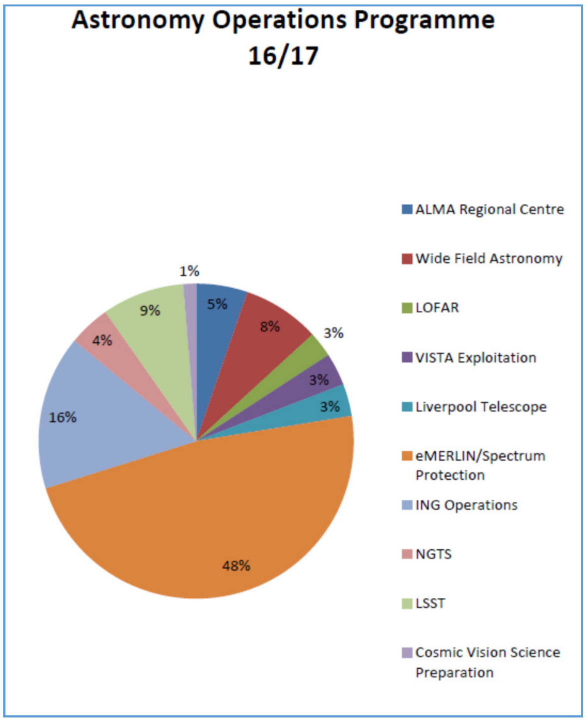
High priority:

- Continued participation in *LSST* (via the LSST:UK consortium). STFC has recently committed resources to UK involvement in LSST, and this should be continued at the projected levels. LSST impacts science across almost all of the astronomy programme.
- *SKA/E-ELT R&D*. STFC should continue to support E-ELT instrumentation development and SKA development at current levels.
- Continued participation in *NGTS* at the currently approved level.
- *ING/WEAVE*. STFC has invested heavily in the WEAVE MOS instrument for the WHT, and should continue this support for the ING to allow science exploitation of this new facility.
- Maintain diversity by providing continued opportunities for new projects via PPRP. A significant fraction of the development budget is understandably allocated to SKA and E-ELT instrumentation, but there is strong community support for sufficient flexibility to exist in the funding schemes (particularly PPRP) to allow participation in other science projects in responsive mode – as successfully demonstrated by STFC leadership/involvement in WEAVE, MOONS, DESI, JCMT, HARPS3, SOXS, etc.; all world-leading projects.

Medium priority:

- Continued operation of *e-MERLIN* (and spectrum protection), with UK access to the facility via PATT.
- Continued operation of the *Liverpool Telescope* at the current levels (with UK access via PATT).
- Continued operations costs for *LOFAR-UK* at current levels.

These priorities are, as would be expected, similar to those from the 2012 programmatic review. ESO continues to be widely viewed across the community as the irreplaceable flagship observational facility to which the UK has access. Likewise, there is a clear community consensus that for observation and theory HPC access is critical for much of UK astronomy, and that exploitation funding remains at a dangerously low level. *These three themes represent our highest priority activities and have a very wide base of community support.*



For the UK to continue to have a scientifically sustainable and balanced astronomy research programme, current exploitation levels must be protected under all funding scenarios (and ideally increase). Pressure on this grant line is already at an all-time high, and there is no scope for future reductions without critically damaging the astronomy science output of the UK.

A balanced astronomy programme also requires diversity in the facilities available, and the flexibility to provide potential access to new projects as opportunities arise.

Good examples since the last AAP report have been the UK-wide access to LSST and STFC involvement in DESI, but there have been other projects of which the panel is aware that have not been successful due to the very tight funding constraints. We argue that maintaining some slack in the PPRP system is a pre-requisite to maintaining a balanced and responsive astronomy programme in the future.

We also note the low cost of operations of many astronomy facilities (shown above). Operations account for less than 1/6 of the astronomy budget, and within that budget many of the current facilities have relatively low costs: Liverpool Telescope and LOFAR are both 3%, the LSST preparation grant is 9%, and even our contribution to ING (which includes access to the WEAVE instrument in the future) is only 16% of the astronomy operations costs. These all represent value for money. The cost savings in closing any of these individual facilities would be very modest compared to the overall astronomy budget – whilst being devastating (and probably unrecoverable) for some science areas.

Our conclusion is that, under a flat cash scenario, the current exploitation grant line must be maintained and the current balance between exploitation, operations and development should continue. Under an increased funding (+5%) scenario, there should be a commensurate increase in exploitation funding compensating in part for the flat-cash environment of the last few years. Additional resources should also be made available through (e.g.) PPRP to fund the smaller projects in which UK astronomy should be strategically investing.

The prospects under a -5% funding scenario are ubiquitously bleak. Given the community's strong desire to protect the exploitation grant line, even at the expense of other parts of the astronomy budget, a -5% global cut would inevitably translate to a funding cut approaching 10% in the development and operations budgets. Such a reduction is not achievable without either the closure/removal of a large facility or programme, or the dramatic scaling back of ongoing R&D for SKA/E-ELT. Both options are unpalatable and would seriously harm the balance and scientific diversity of UK astronomy. Moreover, given the existing international and other commitments to observatories and high-priority instrumentation development, such a cut would fall unevenly within the remaining programme, further eroding the diversity of developments and projects, thus jeopardising future international leadership/standing.

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.*

- What are the key technologies in your area where the UK is world leading and how do they generate benefit for the UK?

- How could STFC support the development of critical technologies that will be essential to support the field in the future?

In answer to the first question on key technologies, the UK is a world leader in the design, development and construction of astronomical instrumentation, both for ground-based and space-borne facilities (with the latter mostly supported via UKSA funding).

The UK has a rich track-record in innovative instrumentation, with our expertise often sought out by our international partners across a broad range of R&D activities. Specific areas where the UK has clear international leadership, and which featured strongly in the community responses, include:

- Detectors: CCD/CMOS detectors, with e2v a notable world leader in detector development. With continued investment, recent progress in IR detectors (e.g. Selex-UK) should provide a European alternative to US vendors, with considerable economic potential beyond astronomy. The UK also has considerable expertise/leadership of mm/sub-mm detectors (e.g. future CMB experiments).

- Adaptive optics (AO): The UK is leading the CANARY pathfinder experiment in La Palma, and a range of other activities (real-time control, algorithms for simulations and analysis) which are vital to the future success of the E-ELT and novel ground-based instruments.

- HPC and software development (also see Q6): An area of significant growth is the processing, analysis, storage, and distribution of 'big data' from astronomical surveys and large-scale simulations; the UK excels in both the hardware and software needed to exploit these, and visualization of such complex datasets has a wide range of commercial applications. The UK also leads development of software to run major international observatories (e.g. ESO's ALMA, and now studies for SKA).

Other areas flagged in the responses included development of optics and sensors for future X-ray missions (e.g. Athena), high-frequency radio receivers (toward SKA), expertise in robotic telescopes (NGTS, LT), cryogenics, ultrahigh vacuum techniques (astrochemistry), and filters for mm/sub-mm astronomy. We also note recent developments in astrophotonics (e.g. on-sky tests of a laser calibration comb led by Heriot Watt).

A response to the questionnaire noted the renaissance of high-altitude balloon experiments, which currently fall in an (altitude) gap between STFC and UKSA. Both these and small-satellite missions can provide cost-effective platforms for novel science, while also raising the technology readiness levels (TRL) for future space missions (with applications in Earth observation science too) and we note this as a future growth area.

These developments benefit the UK economy both directly and indirectly – via the contracts for design and construction of novel instrumentation and facilities, and via the science results and international influence from leading such projects (including fantastic outreach/PE opportunities). These technologies also have a wide range of applications beyond astronomy, e.g., AO in biological microscopy and Earth observation science, sub-mm detectors and image-processing in security and medical imaging, and the use of cutting-edge detectors in cameras for a broad range of commercial applications (e.g. Andor Technology, Raptor Photonics).

To address the second question, a coherent technology strategy (for development of critical technologies across the whole range of TRLs) is required, driven by both the near-term requirements of projects on the roadmap, as well as more disruptive technologies that could result in step changes in future capability.

EU funding has helped to establish/cement UK leadership in some areas in recent years. For example, in ground-based astronomy, the R&D activities coordinated by the OPTICON network and the H2020 Green Flash programme for real-time control in AO. Similarly in space, e.g. the FP7 FISICA programme toward a future far-IR space interferometer. If the UK does not participate in a future H2020-like EU scheme, some of the strategy for early-stage R&D should be revisited.

Moreover, while the EU-funded programmes have been excellent in coordinating early-stage R&D, there is a more general need for funding low TRL activities in the UK, outside of the less flexible consolidated (and consortium) grants, and to include industry where appropriate. (Note that STFC's already oversubscribed PRD scheme targets TRL 3-6.) We support continued efforts for coordinated activity in this area with UKSA, e.g. as one response suggested, the idea of coordinated strategies for detector developments.

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?

- Please comment on how this field generates skills impact for the UK.

In Q3 we concluded that in a flat-cash scenario the current balance between exploitation, operations and development should continue. However, when considering skills there is serious community concern that PDRA positions are very limited in number and to a degree that is not healthy for the long term. Far too often it seems we are ‘paying for gym membership and being unable to afford the bus fare to get there’.

Another structural problem repeatedly identified in the survey responses is the lack of independent early-career fellowships. There are very few UK options for the best PhD students. At the moment this problem is partly being addressed by the Royal Astronomical Society's fellowships scheme. One could argue that the extraordinarily high quality of awardees for a very small number of fellowships indicates there is a large amount of unmet need. The RAS fellowships were only intended as an emergency measure, and STFC should not plan on the assumption that the RAS will necessarily be able to continue this scheme.

Some respondents argued that STFC should allow senior postdoctoral fellows to bid more easily for funding. This would create more demands on resource during a difficult flat-cash funding period but it may encourage innovation by having funding streams open to more than established incumbents. Another imaginative suggestion was to open at least some STFC PhD studentship funding to international applicants (i.e. at the same level as UK students).

STFC deliberately and rightly fund more PhD student training than is needed for long-term academic staff replacement, because of the benefits of having a highly skilled workforce outside the university sector. However, there is some frustration over the lack of structured support for career trajectories out of academia and a desire to increase the skill set in data science. Some early career researchers complain of a lack of skills training in large data handling, data science, project management etc. that are sought-after skills in the commercial world. We welcome the creation of a CDT in Data Intensive Science, and would like to see STFC engage more visibly in joint academia-industry data science training initiatives. In addition to the highly-skilled PhD students and PDRAs working in the field, the development part of the STFC programme builds engineering skills in critical/novel technologies, generating impact to the UK via collaboration and innovation with industry, as well as interdisciplinary applications within universities and with the national laboratories.

There is also an acknowledged need for common user software support, with one respondent remarking "there might be the case for having a few software engineers spread throughout the astronomy departments in the UK, akin to the particle physics community." Astropy is an example of a software package currently developed partly on goodwill and fumes by early career researchers - is this really how astronomy should support its software infrastructure long-term?

A common theme among responses is the need for more staffing in software / engineering / instrumentalists / skilled technicians, with the need for "data science" and software engineering featuring strongly. A particular concern is the need for longer term support for support staff with one respondent remarking "I do worry that support for skilled technicians and engineers has suffered of late as organizations move such posts to temporary support staff and thus avoid long-term employment commitments.” The lack of clear career pathways for technicians and particularly for software engineers was also noted while a few respondents stressed the need to avoid decoupling science exploitation from instrumentation (e.g. at national labs and universities).

Vacuum and surface science (e.g. in laboratory astrochemistry) has a strong and vibrant pipeline into the corresponding global industries, but is under-supported by STFC. One respondent reported that expertise in X-ray detectors stands to be lost through lack of funding. Another reported that the UK is losing skills in astronomical instrumentation. Another reported challenges in universities recruiting and retaining engineers in RF engineering, high speed optical networking and signal processing, big data, image processing.

Several respondents highlighted the difficulties in recruiting and retaining engineering skills on academic salaries, where those skills are sought after by industry. One respondent has had difficulty recruiting opto-mechanical engineers and some specialist technicians; industry value these skills and pay better. Another respondent reported difficulty recruiting staff with "data science" software skills that are much in demand by industry. Many responders pointed out the shortage of long-term funding support and career support for engineering, software, laboratory technicians and data scientists.

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

- Is the current computing resource available for the field adequate?

- What are the foreseen future computing resource needs of the field?

- Do you have access to adequate computing resources for archive/open data support in your field? Please comment on how you consider this will develop in 5 years.

The overwhelming majority of applicants thought that, while their computing needs were currently (more or less) met, they felt that this would not be the case in the future without future investment. The current DIRAC2 system was widely thought to be a success, with respondents noting high profile results from the system. It is seen as a requirement for the UK to retain its lead in theory/numerical simulations. Several responses emphasized the high impact per expenditure that derives from this type of work. However, there are concerns in other replies that the allocation of computing time on DIRAC was too small for their needs. Some respondents commented that they required small local clusters for interactive work, and that this was not provided through the DIRAC system. Concern about storage and archiving of data was widespread.

In the vast majority of cases, respondents thought that their computing needs would increase significantly, and that this would be problematic for their research. There was considerable uncertainty about the future of high performance computing, with several respondents seeming to believe that DiRAC-3 was already funded. In this scenario they felt that the available resources would be adequate, but – of course – DIRAC3 is not yet funded. Many respondents highlighted a future need for high-throughput computing (HTC), and wondered how this would be met within the current STFC strategy. We note that many observational programmes (for example, 3rd generation VLT instruments, LSST, etc.) require increasing access to HPC/HTC for batch processing of complex data sets and their calibration. Only a tiny fraction of respondents did not foresee a major increase in their computing needs.

In addition to responses that focussed on computing hardware, many respondents highlighted the need for software support in order to make optimal use of the facilities available. There was widespread support for increasing numbers of software engineers and data scientists, and a feeling that these people particularly needed stable career paths. This was seen as essential in order to retain such skilled staff in the long term, and to ensure the transfer of knowledge between projects. Applicants also called for greater training in software engineering for PhD students.

A number of participants expressed concern about the lack of an archival data storage system. Some felt that this was required in order to comply with the open access research policy. For observational projects, this can be largely catered for using existing observatory archives (for the raw data) and repositories such as CDS from the final data products. However, such facilities do not generally exist for the very large datasets generated by computer simulation projects. A number of respondents interpreted the open access policy as including all intermediate `derived' datasets, and thought the current provision inadequate: respondents commented they simply did not have the storage capacity (or the funds to pay for it) at their institutions in order to meet the requirement. If this were the case, as data volumes increase it may be difficult to keep pace with the required storage, and it may be better to accept that large volume data streams (such as numerical simulations, or raw SKA data streams) will need to be compressed prior to being archived. If new analysis cannot be undertaken from the compressed data, it would then be necessary to recomputed or re-observe. The balance of storage versus computation should be carefully assessed in the light of a realistic interpretation of the open access policy.