What do astronomers want from the STFC?

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Stephen Serjeant and the STFC's **Astronomy Advisory Panel** summarize community responses to its consultation on research priorities, undertaken in November 2018.

1 (Above) Continued membership of the European Southern Observatory, including participation in the ELT, is critical to UK astronomers. (ESO/L Calçada) **2** (Right) Powerful computing requirements such as DiRAC are also hugely important. (STFC/DiRAC)

These are difficult times. Observational and theoretical astronomy are fast-paced fields in which progress depends on a broad range of long-term, large-scale facility investments, from international observatories to high-performance computing. There is, therefore, an inevitable tension between exploitation funding and that for operations and development, made all the more difficult by the flat-cash funding regime in place since 2010. As the UK Science and Technology Facilities Council (STFC) Astronomy Advisory Panel (AAP) quoted in its 2016 report on the balance of the astronomy programme, the pressure on exploitation combined with the essential facility and development spending has put astronomical research in the position of "paying for gym membership and being unable to afford the bus fare to get there", also summarized as "batteries not included" syndrome.

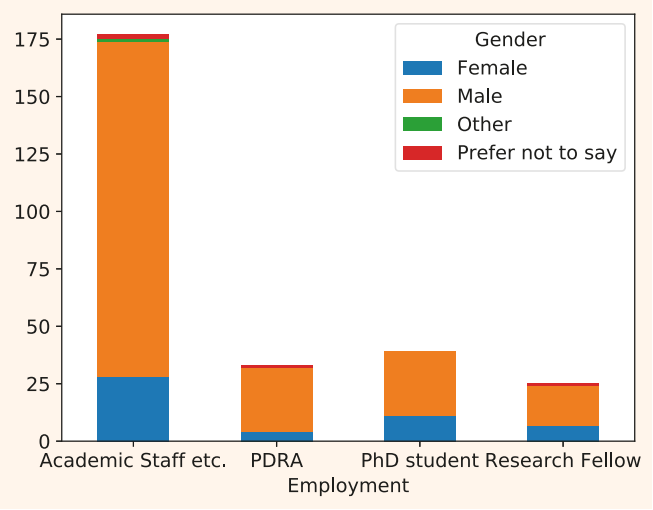
The STFC will soon be starting its second Balance of Programmes review, where it will grapple with the consequences of continuing flat-cash funding. Evaluation panels have been set up in all STFC areas including astronomy. The AAP and the Solar System Advisory Panel were asked to update STFC on changes in their areas (e.g. scientific priorities, altered prioritization of experiments or projects), what would be gained or lost in ±10% funding scenarios and any new or emerging opportunities in addition to the projects already shortlisted in the STFC Priority Project submissions last year (https://stfc.ukri.org/files/projects-summary-list).

The advisory panels consulted with their communities to provide inputs over a period of seven weeks in autumn 2018; we are grateful for the prompt responses from the community, which we summarize here. This community response formed the basis of our AAP response to STFC on your behalf. This article and our report represent our reflection of your views, rather than the views of STFC. Please note also that this article covers the AAP remit only and so does not include the views of the solar and planetary communities.

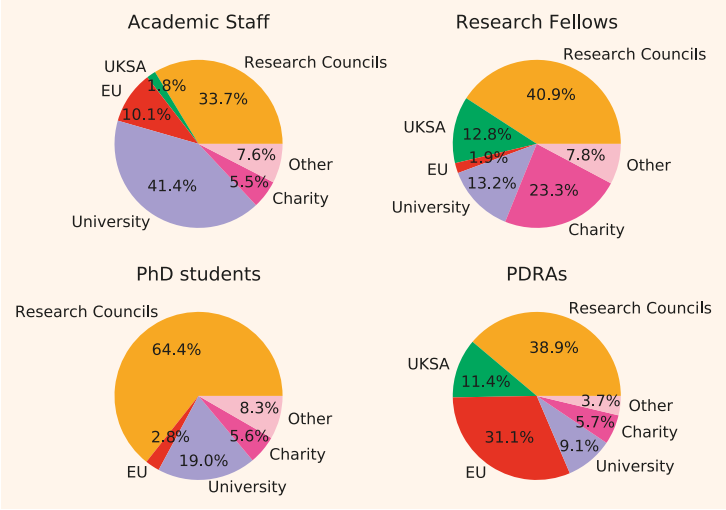
The continued flat-cash funding settlement has placed increasingly difficult constraints on STFC activities including the community's top priority, exploitation, i.e. research grants. But there are other pressures. The policy environment is at risk of rapid and unpredictable changes, and not just for astronomy. Exiting the European Union (EU) creates serious challenges for STFC's core programme, not just in funding (given that EU funding is significant for astronomy) but also in mobility, collaboration and international leadership, as outlined in a 2018 Royal Astronomical Society response to the House of Commons Science and Technology Committee summit on Brexit, Science and Innovation (https://bit.ly/2Xkak8U). We're pleased that the Astronomy Evaluation Panel has asked heads of departments to quantify the national proportion of EU-funded postdocs, and we welcome STFC's consultation exercise on the future of consolidated grants.

"We welcome the government's aspiration to boost spending on R&D"

We have also taken into account the international nature of astronomy: facilities are often international in both location and funding. As the AAP stated in 2016: "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."



3 Histogram of respondents by employment status and gender.



4 Total funding by employment. No PhD student reported UKSA funding. Note the strong reliance on EU-funded PDRA effort. Nearly all PDRAs who reported their funding sources declared 100% of their funding from a single category.

We also welcome the government's aspiration to boost spending on research and development (R&D) to 2.4% of gross domestic product (GDP) by 2027 (https://bit.ly/2zZht3r), given the UK's relatively low historical funding compared to most of the G8, the Euro area and the world (World Bank, https://bit.ly/2BSHYK3), noting, as the Russell Group of universities has (https://bit.ly/2TgMI5T), that government-funded research leverages much greater private investment. Nevertheless, the UK has seen an overall decline in successful European Research Council (ERC) bids since 2017 (*Times Higher Education Supplement*, https://bit.ly/2H5HfIR) and, according to Dan Hodges of Innovate UK (https://bit.ly/2SmrBKR), UK research spending as a percentage of GDP (including industrial research) is static.

Our consultation

We had 293 respondents to our questionnaire, who provided demographic data as well as information about their funding situation and research priorities, but this represents only a small portion of the eligible community. The 2016 demographic survey undertaken by the RAS (https://bit.ly/2SWqoz2), for example, estimated the total UK astronomy community at 527 academic staff, 546 research staff and 237 technical staff. Our consultation was time-limited; a longer period would have helped reach more of the community, but some "survey fatigue" may have played a part.

The gender and seniority breakdown of our respondents (where provided), is shown in figure 3. The population is dominated by academic staff, whose male:female ratio is broadly consistent with the RAS demographic survey. Female postdoctoral researchers appear to be under-represented in the consultation, compared to an expectation of a ~27% female cohort at this level from the RAS data. Future consultations may be able to avoid this by advertising through channels that are explicitly inclusive of women.

The geographical locations of respondents in the UK and Republic of Ireland, where given, indicated neither comprehensive nor fully representative coverage. This is consistent with the accelerated consultation timescale negatively affecting the community response rate. As well as UK respondents, we had eight responses from people affiliated fully or partially with institutions outside the UK.

"This question collected a census of 'critical' facilities for current and future studies"

We asked you what your current balance of funding is. The total funding reported by the community (summing fractional contributions from each respondent in each category) is shown in figure 4, as the funding profile for a mean-average individual. 178 respondents quoted their funding profiles. These funding proportions will not necessarily be the same as that for the cohort as a whole, since the latter is weighted by the total funding each individual receives. The results emphasize the very strong reliance in UK astronomy on EU-funded postdoctoral research assistants (PDRAs) in recent years. Our figures show 31.1% from the EU, 38.9% from Research Councils UK and 11.4% from UKSA; for reference, the 2016 RAS demographic survey quoted PDRA funding splits of 51% (RCUK), 3% (UKSA), 27% (EU), 5% (University), 14% (Charity and Other). Nearly all PDRAs and PhD students and the majority of research fellows who reported their funding sources declared 100% of their funding from one of the categories.

We also asked what areas you worked in, mapped onto the new STFC Science Challenges. By far the most populous challenge is A5: How do stars and galaxies evolve? Some of you thought this should be (re-)broken into separate challenges. We also asked you whether these challenges should change. Most respondents did not address this question, or thought no changes were necessary (226, 77%). Areas generally related to stellar evolution (including, for example, supernova explosions, transient electromagnetic observations of gravitational waves) have been identified as requiring revision in the list of important scientific questions in 30 out of 78 suggested changes. Five respondents noted that many aspects of extreme environment astrophysics no longer fit clearly into the stated themes.

We asked what your crucial facilities are in the next five-plus years. Of the 293 respondents, 274 answered, identifying more than 90 different facilities (observing, computational and experimental) for their current and long-term research activities. Some of these are in operation (or operating but requiring development), or are future facilities; there are also those that are STFC-funded through projects or exploitation as well as UKSA and other, largely international, non-STFC facilities.

We have classified the responses we received in order to assess their importance. We have identified an "interest" in a facility on the basis of a single mention by a respondent, and all respondents identified several facilities in their answers, emphasizing the importance of the multifacility and multiwavelength nature of contemporary astrophysics and cosmology.

In contrast to previous years, this question collected a census of "critical" facilities of use to current and future studies; as such, it may not be complete in context or facility. We did not specifically ask for comments on the Extremely Large Telescope (ELT), Square Kilometre Array (SKA) and other R&D programmes and

The UK Space Agency

Our remit on the AAP is formally limited to the STFC, but several questionnaire responses commented on UK Space Agency (UKSA) matters. Astronomy is naturally both ground-based and space-based, so where appropriate we also comment here on the space agency. UKSA continues to be underfunded, particularly in payload provision and scope for bilaterals, reducing the opportunities for UK space-science leadership. AAP has also not altered its 2016 view that the decision-making processes, consultative structures and committee memberships within UKSA are opaque compared to those of STFC, though we welcome the steps made to improve this since 2016.

therefore cannot comment on any overall change in perception on these elements of the STFC programme.

The interest in facilities and capabilities, as defined by the responses, are summarized below. These largely support the identified priorities specified in the 2016 AAP consultation (https://bit.ly/2SpjZrg). But the nature of the question asked was different in this case: we asked in terms of a poll, rather than prioritization with justification as in 2016, so the results are not directly comparable. Furthermore, in a separate consultation, the STFC's Astronomy Evaluation Panel has requested responses from facilities and projects, so we have restricted our analysis to community interest in projects and facilities. We note that space-based astronomy may be underrepresented in this STFC consultation.

Highest interest

The majority of respondents listed continued membership of ESO (figure 1) including participation in the ELT, access to Paranal (including the Very Large Telescope Interferometer), La Silla and the Atacama Large Millimetre–submillimetre Array (ALMA), including the submillimetre pathfinder APEX, as a critical element of their current and future requirements. This supports continued access to ESO and ALMA across science areas, and includes development of ESO facilities and instrumentation as a critical need in the near and long term.

Development and provision of High Performance and High Throughput Computing capability (HPC and HTC), including Distributer Research utilising Advanced Computing (DiRAC) was also identified as of the highest interest (figure 2). These are needed for theoretical simulations, modelling and for processing and storing large volume and highly sampled observational data, and was strongly identified (explicitly or implicitly) as a critical priority.

High interest

Many respondents supported continued membership of the Large Synoptic Survey Telescope (LSST), suggesting that the current level of support enabled through the STFC Projects Peer Review Panel award LSST:UK has been fruitful. A similar level of support was expressed for Isaac Newton Group (ING) facilities, including the William Herschel Telescope and the new multi-object spectrograph WEAVE, the Isaac Newton Telescope and planet-hunting spectrograph HARPS-3, but also interest at a lower level in the wider capabilities on offer at La Palma including the Telescopio Nazionale Galileo (with spectrograph HARPS-N) and the Gravitational Wave Optical Transient Observatory (GOTO). The ING was identified as being useful for technological and instrumentation R&D and should not be lost from the UK portfolio. Several responses specified the need for facilities in both northern and southern hemispheres. After the UK withdrew from Mauna Kea, the ING and telescope access through the European network OPTICON (funded through Horizon 2020) remains our only means of securing northern targets without relying on open-skies policies from non-UK international observatories. Notably there was significant interest in non-UK optical–infrared facilities in the north, including Keck, Subaru, Large Binocular Telescope, Gran Telescopio Canarias, Thirty Meter Telescope, Gemini, Kitt Peak National Observatory and the Dark Energy Spectroscopic Instrument (DESI), Pan-STARRS, Sloan Digital Sky Survey V, and the UK Infrared Telescope.

"The majority of respondents listed continued membership of ESO as critical"

There was also high interest in continued access to and development of radio facilities including SKA precursors and continued leadership within the SKA itself. In particular, most respondents strongly supported e-MERLIN and LOFAR, and the SKA pathfinders (MeerKAT, ASKAP, Murchison Widefield Array) as well as access to very long baseline interferometry (VLBI) through the European VLBI Network, the US Very Large Array and its planned expansion (eVLA), the Giant Metrewave Radio Telescope in India, and the Australian Telescope Compact Array (ATCA). The interest expressed reflects and supports the recommendations of the 2017 UK Radio Astronomy Strategic Review (https://bit.ly/2BNRGx2). The panel speculated that the response from the radio community was lower than expected because their review was held only recently.

The James Webb Space Telescope (JWST) is a priority facility for future exploitation, building on the legacy of the Hubble Space Telescope. Funds for HST exploitation in the near term and capitalizing on STFC and UKSA's investment in the JWST should be a priority. In the long term, the lack of facilities for ultraviolet astronomy remains a concern; potential future involvement in projects such as the Canadian Cosmological Advanced Survey Telescope for Optical and UV Research (CASTOR) and/or NASA's Large UV/Optical/IR Surveyor (LUVOIR) could address this.

Significant interest

Involvement and exploitation in a wide range of ESA and NASA missions with UKSA support had significant interest, with Gaia and Euclid as priorities. Responses identified sustained funding of Euclid in pre-operational phases and exploitation for both missions as essential together with exploitation for Gaia, Spitzer-warm and Herschel legacy data.

The exoplanet community showed highest interest in ESA's Planetary Transits and Oscillations of Stars (PLATO), the Next Generation Transit Survey (NGTS) at Paranal, NASA's Transiting Exoplanet Survey Satellite (TESS) and ESA's Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL). There was less interest in ESA's Characterising Exoplanet Satellite (CHEOPS), SuperWASP, the ESO habitable-planet search instruments Speculoos/TRAPPIST, and commercial mission Twinkle. UK scientists are playing leadership roles in both PLATO and ARIEL, which need support, complemented by ground-based facilities such as NGTS.

There was strong support for the continuation of high-energy facilities such as NASA's Neil Gehrels Swift Observatory, ESA's XMM-Newton and NASA's Chandra, again with exploitation support; the consultation also showed significant interest in NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) and gamma-ray observatory FERMI, and ESA's gamma-ray observatory INTEGRAL. In the longer term, there was strong support for the proposed Athena X-ray observatory, followed by the THESEUS high-energy transient mission proposal, the Space Variable Objects Monitor SVOM, NASA's X-ray imaging and spectrometry mission XRISM, and the German e-ROSITA X-ray mission.

Further interest in the JWST came from the effect of the small contribution to the James Clerk Maxwell Telescope operating costs in leveraging UK leadership in high-profile science results, suggesting that other far-IR-to-mm facilities, such as exploitation of Spitzer-warm data and archival Herschel data, with a forward look

to the European/Japanese Space Infrared Telescope for Cosmology and Astrophysics (SPICA) mission, should also be supported. Facilities such as the European millimetre wavelength IRAM/NOEMA facilities, the US Submillimeter Array (SMA), Large Millimeter telescope in Mexico and – for the future – the Advanced Technology Large Aperture Space Telescope concept, were also mentioned.

Similar interest was shown in the Liverpool Telescope (LT) for continued operation at the current levels; there was also interest in the New Robotic Telescope (NRT) and other robotic telescopes such as the Las Cumbres Observatory (LCO) network.

In contrast to our 2016 consultation, in 2018 we saw an emerging interest in gravitational-wave interferometry from LIGO/Virgo, with support for multimessenger localization telescopes and networks such as GOTO, the BlackGEM telescope at La Silla, LT/NRT, LCO projects and, taking the long view, the ESA/NASA Laser Interferometer Space Antenna (LISA). LIGO/Virgo and LISA fall in the remit of other advisory panels, thus the UK interest in this poll may be under-represented, but STFC can take a leading role in ensuring UK participation in localization across all wavelengths. Wide-field, rapid-response capability, particularly on moderate size (1–4 m) telescopes will be invaluable in this domain.

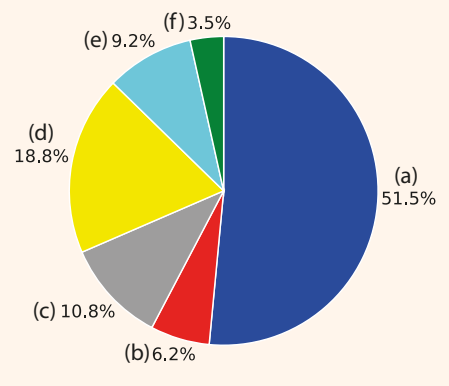
Only one response made explicit mention of the Cherenkov Telescope Array; again it may be that the community regarded this as being within the remit of the Particle Astrophysics Advisory Panel. Respondents with interests in the cosmic microwave background all specified the Simons Observatory as of high priority.

Several responses referred to the importance of continued detector and instrumentation R&D (for both the ELT and SKA and for novel projects), support for laboratory astrophysics and testbeds, including microgravity environments. STFC's Projects Peer Review Panel (PPRP) provides a mechanism to enable such projects to develop and provide corresponding resources.

High-priority areas identified for continued support in the responses also included computational support in the form of software development, archives, virtual observatories and survey support from the Cambridge Astronomical Survey Unit (CASU) and the Wide Field Astronomy Unit (WFAU) for a large fraction of the large surveys being undertaken by UK scientists.

These responses demonstrate that closer association between UKSA and STFC funding for R&D, instrumentation and exploitation must be the basis for future missions. We should be building on huge successes for the UK community through Herschel, JWST, Gaia and Euclid to fully realize this potential. Better coordination of both the pre-operations, operational and archive phases is the means to deliver first-class science. Weakened funding in any of these areas potentially risks loss of return for the critical investment made.

5 Summary of preferred budget rebalancing options in the event of continued flat-cash funding. The response rate to this question was 89% (260/293). The exploitation line: (a) should be increased only if there is new money; (b) should be increased at the expense of operations; (c) should be increased at the expense of astronomy development; (d) should be increased at the expense of both operations and development; (e) should not change; (f) is too high.



We note here (as in our 2016 report) comments regarding the need for better alignment of exploitation (i.e. grants) with facility funding. The responses to our survey demonstrate the breadth of the programmes accessible to UK astronomers and the successes and leadership enabled by continued STFC commitment through the PPRP line, including ELT R&D, LSST, DESI and SKA.

"Lack of exploitation funding is particularly damaging for early-career researchers"

Balancing new budgets

We asked you how STFC should respond to budget changes. Out of the 260 responses, 52% would increase the grants line only if there is new money (see figure 5). There was a strong message that exploitation is badly underfunded: just 12% of the respondents suggested that the current exploitation budget is adequate or too high – a result very much in line with the outcome of the previous community consultation. We recognized some frustration from the community that this message appears not to have been heard. Many responses pointed out that under-resourced exploitation is a symptom of chronic underfunding of the entire astronomy programme.

In this context, there was a mixed response to the possibility of cutting operations and/or development in order to provide more money for exploitation. Just over a third of respondents (36%) favoured this route, but most were instead cautious about rebalancing the existing budget in a flat-cash environment. Many expressed concern that reducing operations and/or development funding would be damaging in the long term, limiting the new science available to be exploited in the future.

If there were to be a budget uplift, it was felt exploitation should receive the largest boost, but operations and development should be increased too. Most (69%) wanted to see at least a 5% increase in the exploitation budget. But many respondents noted that these three strands are interlinked: exploitation is not possible without continued investment in development and operations, and vice versa. And adequate funding for blue-skies research was seen as vital for maintaining quality and innovation. Another common theme was that blindly targeting large amounts of money at facilities that generate relatively little or low impact science is very inefficient. There was also a strong message that the budget should not be cut – to do so would be disastrous – but in the event of a 10% cut, most thought exploitation and (to a lesser extent) operations funding should be prioritized ahead of development.

Many respondents pointed out that the lack of exploitation funding is particularly damaging for early-career researchers. Without adequate funding for postdoctoral positions, early-career researchers are moving overseas or leaving the field entirely. This is extremely worrying for the long-term health of the community: these are the people that do the bulk of the research and who will be, in the future, using and developing the facilities that are now being invested in.

Finally, Brexit and access to EU funding is a key consideration. A lot of existing exploitation funding comes from ERC grants (figure 4), and this has helped prop up the community in the face of declining STFC support over the last decade. If the EU funding stream is lost without a significant uplift to exploitation, then UK astronomy will be hugely damaged.

Opinions about excellence

We asked specifically whether the grants line should actively prioritize particular research areas, or whether the current practice should be maintained of allocating resource only on the evaluation of scientific excellence. The overwhelming view (89%) was to fund on scientific excellence only.

Among the 249 individuals who support funding on scientific excellence only, there are many very frank views expressed in the free-form narrative, not just pointing

"We have already invested heavily in multiscience facilities. We require multiscience exploitation capability to make this investment pay. No single community deserves special attention or privilege as we can't forecast where the most exciting/important discoveries will come from"

out the difficulties in creating a process to identify priority areas and guessing the winners, but also in the resulting consequent lack of responsiveness, as well as potential damage to the UK's research reputation. Some examples: "Very dangerous! The most important scientific discoveries have been based on serendipity and a blue-skies approach"; "I have never seen any evidence that targeted funding gets better scientific returns"; "Ring fencing exploitation for specific science areas or facilities can NEVER support better science outcomes for the available funding"; "Ring-fencing the budget for certain areas is a recipe for low-quality science"; "That way lies conservatism, mediocrity, decay and corruption … all with the power would choose to protect their own vested interests"; "Choosing specific areas results in ambulance chasing, and those with vested interests pushing their own agendas"; "Choosing winners always shrinks the pool and narrows opportunities in the long term"; "I feel very very very strongly that blue-skies research must not be directed. You don't know where the great results will come from, but you do know who is doing the best science, and they are the people who should be funded."

Among the 31 supporters of a more prioritized approach, the most popular reasons were to support facility investments, such as LSST, Euclid, JWST and ESA missions in general. One respondent expressed a wish for more scope for investment at the project R&D level. Another suggested dividing the grants line into two pots (presumably priority areas and excellence-only), and one of the opposers of prioritized funding had a similar suggestion. Other comments included: "A more strategic view of where to invest would not lead to a fall in scientific excellence, but would mean we build on our development and operations investments"; "We need to be ruthless and choose what we need to do"; "I fear the current model just doesn't work after a decade of hits on the budget (in real terms)."

One opponent of prioritized funding added the following caveat (presumably assuming a funding uplift): "However, many focused calls that cover the main research areas and facilities in the UK in rotation might work okay, although there is significant risk to research productivity. A significant negative of the current consolidated grants is that they are only once every three years, which requires the right data at the right time to get support – funding calls on a shorter cycle to give a higher cadence would be good."

We also asked you about new opportunities, beyond those already identified in the recent STFC Priority Programmes call. A total of 112 (38%) responses were received. The breadth of the UK astronomy community was reflected in the diverse distribution of responses. In terms of broad new themes: 8% of respondents mentioned gravitational-wave transients follow-up as high priority; 5% encouraged more projects using cube/small-sats and high-altitude platforms; 4% urged that bilateral collaborations with nations beyond Europe would be beneficial in the post-Brexit research landscape, and also wished to see closer UKSA collaboration strategies.

Respondents mentioned the following new and forthcoming projects and initiatives: 4MOST, ARIEL, Athena, ATLAS, ATLAST, CASTOR, CHEOPS, CHIME, ELT, eROSITA, Euclid, eXTP, HERA, HIRAX, IXPE, JWST, LiteBIRD, LSST, LUVOIR, MESSIER, PFI, PIXIE, PRISTINE, Quantum sensors, SDSS-V, Space Communication, Speculoos, SPICA, SuperBIT, SVOM, Theseus, Twinkle, VLBI and XRISM, among others. We include here only future facilities and those not already submitted to the Priority Programmes consultation.

But 20% of respondents also expressed the view that limited funding is best utilized by supporting science exploitation, instead of spreading ourselves too thin and searching for new priorities. This includes the respondents who wished to see further support for high-performance computing and novel computation and data facilities. Again, there is some community confusion as to why ideas are sought for new opportunities when the top priority is so stretched, though a plausible answer from the STFC would be that it has listened and preserved the grants line as best it can, in very difficult times. There is also the unfortunate but pragmatic approach that presenting a bank of sparkly new possibilities is more likely to turn the head of someone with new money than more of the same.

Summary

In summary, the community is clear that exploitation funding should increase. The grants line is already stretched and is declining in real terms, and any further reduction will be very damaging to the international competitiveness of UK astronomy and astrophysics. This has a disproportionate effect on early-career researchers, leading many to seek employment overseas or outside the field, affecting the long-term health and competitiveness of UK astronomy. While the vast majority of the community wants to see an increase in exploitation funding, most also felt this should not come at the expense of development or operations. There is a very clear community consensus against restricting or prioritizing Astronomy Grants Panel funds to particular areas.

The community also sees that the core programme is critically underfunded and there are no options for a reduction in the programme without damaging internationally important activity. However, there is no community consensus for where one might target such reductions in the core programme. A decrease would result in the loss of consortia memberships and access to state-of-the art facilities.

Science exploitation of STFC facilities is now strongly dependent on EU funding. If the UK loses access to EU funding without a corresponding uplift to the exploitation budget, the UK will not maintain its current level of international leadership.

We thank all those who responded so promptly and so fully to our consultation, which has once again reflected the intense pressure on exploitation funding. As a minimum, a *prima facie* case can be made that flat-cash research council funding is already eroding the UK science base. And the prevailing community view of our priorities amid the difficult choices that we face were contained in this succinct comment from one of our respondents at the end of 2018: "We have already invested heavily in multiscience facilities. We require multiscience exploitation capability to make this investment pay. No single community deserves special attention or privilege as we can't forecast where the most exciting/important discoveries will come from." This is, above all, the message that the AAP took to the STFC. ●

AUTHORS

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