Particle Astrophysics Advisory Panel
Response to BIS Capital Consultation
4 July 2014

Please find below a response to the BIS open consultation "Science and research: proposals for long-term capital investment". This response was prepared by the STFC's Particle Astrophysics Advisory Panel, comprised of

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4. KEY QUESTION: What balance should we strike between meeting capital requirements at the individual research project and institution level, relative to the need for large-scale investments at national and international levels? (1000 words maximum)

Both large scale investments at national & international level and investment at the level of individual research projects and institutions are important. Particle Astrophysics projects typically require large-scale international collaboration and investment, and therefore most funding is needed in this category. To maximise the scientific output of this investment some funding is also required at a more local level, in particular for HPC facilities. There should also be some support for small-scale projects.

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5. How can we maximise collaboration, equipment sharing, and access to industry to ensure we make the most of this investment? (1000 words maximum)

Collaboration and equipment sharing are already common in Particle Astrophysics due to the scale of the projects (both experimental and computational). There is also collaboration/sharing between projects. For instance the proposed materials screening facility, which is key for dark matter direct detection, would also be valuable for a range of other low-background experiments (e.g. double beta decay). The hardware for the DiRAC and GRIDPP shared national computing facilities were developed around the problems being tackled. It is crucial that capital investments are well publicised so that researchers are aware of what is available. A pool of data acquisition electronics (similar to the previous "Rutherford Loan Pool") would be useful, in particular for evaluating the suitability of particular modules. Individual universities already organise events that bring together academics from different disciplines and industry. Nationally, public discussion meetings and showcasing events could enhance access to industry. Industry days held recently (for example) for SKA and CTA are an effective way to connect industrial and scientific partners and to make clear what opportunities exist.

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6. What factors should we consider when determining the research capital requirement of the higher education estate? (1000 words maximum)

Infrastructure in the Higher Education Estate across the country underpins research and technological development related to multiple projects. On one side, laboratories and computer infrastructure in Universities are needed to develop key components of large and medium-size

research projects in particle astrophysics, on the other they provide the infrastructure to develop blue-sky technology which goes beyond the state of the art and can have important implications for future particle astrophysics projects. Examples are ultra-clean laboratory facilities for low background experiments such as dark matter and neutrino-less double beta decay experiments and large computing infrastructure which is essential for all particle astrophysics research, both experimental and theoretical.

Key aspects which need to be considered are:
- the balance between project-specific capital investment, via Research Councils, multi-project infrastructure located at higher education institutions and capital for blue sky technological development;
- the sharing of resources and the collaboration among researchers, multiple projects and different institutions, such as collaborative networks of universities;
- the potential for knowledge transfer with industry, but at the same time maintaining some space for blue-sky longer-term research developments;
- the long term sustainability of the capital investment. For instance, the recurrent costs to maintain the use of the facilities which have been funded, e.g. electricity costs for large computing infrastructure;
- the impact on training of the current and new generation of researchers.

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7. Should - subject to state aids and other considerations - science and research capital be extended to Research and Technology Organisations and Independent Research Organisations when there are wider benefits for doing so? (1000 words maximum)

Significant capital investment in Independent Research Organisations, such as e.g. CERN, typically provide very significant impact in national and, even more so, in large international projects, positioning the UK as one of the leaders in such endeavours. Such funding should be peer-reviewed and aligned with the scientific priorities of the community.

Capital investment in Research and Technology Organisations can play an important role in fostering knowledge transfer with industry, but should not be given at the expenses of funding to Research Councils and Higher Education institutions. Any such funding request should be fully justified on scientific grounds and in terms of benefit to society, and should be subject to a rigorous review process as is the case for purely scientific projects. It can be expected that such capital investment is match-funded by the private sector.

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8. KEY QUESTION: What should be the UK's priorities for large scale capital investments in the national interest, including where appropriate collaborating in international projects? (1000 words maximum)

The UK's priorities for large scale capital investments should be based on scientific excellence, UK leadership, impact, and programme balance. The STFC's recent Programmatic Review highlighted three world-leading infrastructures in particle astrophysics where capital funds could be used to deliver UK leadership and world-class science. In the order in which resources would be required, these are:
- Direct dark matter detection: LUX-ZEPLIN and enhancements to the Boulby Underground Laboratory
- Gamma-ray astronomy: the Cherenkov Telescope Array (CTA)
- Gravitational waves: upgrades to Advanced LIGO

Investment in these areas would realise recommendation R15 of the Programmatic Review: "We recommend that maintaining involvement in gravitational wave, dark matter, and high energy gamma ray experiments be a priority for the sake of the diversity of the UK programme."

Direct Dark Matter Searches were strongly endorsed in the Programmatic Review, and more recently in the US P5 report, which calls for immediate commencement of tonne-scale experiments. The UK community has converged on the LUX-ZEPLIN project, with participants including Daresbury, Edinburgh, Imperial, Liverpool, Oxford, RAL, Sheffield, and UCL. The UK holds significant leadership roles and brings a track record in pioneering world-leading technology. In addition, the Boulby Underground Laboratory is a vital UK infrastructure to underpin dark matter searches. It provides material screening at world-class sensitivity levels, acts as a training ground for highly skilled scientists, and hosts dark matter work in the UK funded by international partners.

The long-term future of dark matter searches will see an even stronger coordinated world-wide programme. For the UK to play a future major role we propose:
- Investment in xenon, the core of the LUX-ZEPLIN detector. Xenon is a non-perishable asset that could support both LUX-ZEPLIN and future opportunities, such as third-generation dark matter experiments, sterile neutrino searches, MEG-style experiments, and general R&D in particle physics.
- Investment in upgrades to the world-class screening facility at Boulby, needed for delivering key components to any dark matter detector and also beneficial for other low-background experiments.
We note that these investments would benefit several areas of particle astrophysics and particle physics research.

The Cherenkov Telescope Array (CTA) is a 27 nation effort involving over 1000 scientists to build a global observatory for the highest energy photons. Currently in the preparatory phase, CTA will consist of 120 telescopes distributed over two sites. As the first open observatory at very high energies, CTA will provide a census of particle acceleration in the universe, explore the role of high energy particles in feedback processes, probe extreme environments from close to black holes to cosmic voids, and search for dark matter and quantum gravity effects. The complementary nature of the CTA dark matter search to direct detection and LHC searches was recognised by the US P5 report and several roadmaps. Approximately 60 UK scientists and engineers are involved in the project, at Durham, Hertfordshire, King's College London, Leicester, Liverpool, Liverpool John Moores, Nottingham, Oxford, Sheffield and Southampton. UK leadership roles include the Project Scientist, the leader of the small-sized telescope sub-project (70 telescopes), and the leadership of the first CTA prototype camera.

CTA is a key instrument for global particle astrophysics and features on the ASPERA, ASTRONET and ESFRI roadmaps (and is one of the subset of ESFRI projects which is eligible for major H2020 support). Consolidation of the UK's leading role in CTA requires investment: we recommend of order £1M per year of capital investment over the full period to 2020-21 will be required for the UK build of key systems. Such investment would secure CTA data access for all UK scientists. We note the UK's strong hardware role in the small-sized telescopes and partnerships with UK high-tech industry.

Advanced LIGO is expected to yield the first direct observations of gravitational waves. Consisting of two 4 km interferometers in the US, with a third proposed for India, first science operations will be in 2015, and design sensitivity is expected to be reached near the end of the decade. Advanced LIGO will be sensitive to the merger of neutron star binaries to a typical distance of 200 Mpc, with a best-estimate rate of 40 events per year. Other possible sources include black hole mergers, pulsars, supernovae, GRBs, cosmic strings, and stochastic GW backgrounds. Approximately 100 UK researchers are involved in Advanced LIGO, at the Universities of Glasgow, Cardiff, Birmingham, Southampton, Sheffield, Strathclyde, Cambridge and West of Scotland, and the Rutherford Appleton

Laboratories. UK scientists occupy a large fraction of leadership roles in the LIGO Scientific Collaboration, including co-chairs of 2 of the 4 search groups. UK development of mechanical and optical technology for Advanced LIGO has gained the UK partnership in this major project and ensured data access for UK scientists. UK scientists also lead an international team exploring upgrades to the baseline design.

We propose capital investment in Advanced LIGO upgrades as part of a programme coordinated with international partners. Specifically, we propose capital investment for designing, testing and supplying the hardware for heavier mirrors, with coatings of lower thermal noise, and fused silica suspensions of enhanced thermal noise performance. This builds on existing expertise developed across the breadth of the UK groups in this area. The estimated scale is £12-15M over 2018-21. Scientific benefits would be to extend the distance reach of Advanced LIGO up to a factor of 3, increasing the signal detection rate by a factor of 30, and extending Advanced LIGO's sensitive band to lower frequencies.

Further notes:

1) The recent selection of a gravitational wave detector for the ESA L3 slot presents an excellent opportunity for UK scientists. UK groups have been major contributors of flight hardware for LISA Pathfinder, positioning the UK for a prominent role in the eventual eLISA mission and its associated science return. However, capital support needs to be found to maintain UK capability between the LISA Pathfinder launch in 2015 and the potential availability of UKSA funding following a specific mission proposal c.2018-19.

2) Computing Infrastructure: The Particle Astrophysics Advisory Panel recognises the need for access to HPC and HTC across many particle astrophysics areas. We broadly support capital investment in computing infrastructure, and recommend a balance be sought between centralised large-scale resources for production work (such as Dirac3 and ARCHER), and institution-level resources for prototyping.

3) Strong synergies exist with projects recommended by the Astrophysics Advisory Panel and capital investment is clearly highly desirable to support the construction of the major observatories of the next decades, including SKA, CTA, LSST and Athena.

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9. What should the criteria for prioritising projects look like? (1000 words maximum)

We believe that the main criteria are
1) Scientific excellence/return
2) UK leadership
3) Societal and economic impact
4) Programme balance, both in terms of overall scientific breadth and balance between high risk / high return and guaranteed science
5) International support / presence on key roadmaps / potential for leveraging of European or international funds.

STFC has comprehensively considered its priorities for investment during the recent programmatic review (PR), using criteria similar to those above. The presence of projects in the PR recommendations should therefore be the primary guide, but we note that new opportunities in the PA area, namely the planned enhancements to Advanced LIGO from 2019, and improvements to the materials screening facility at Boulby, were not considered by the PR.

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10. Are there new potential high priority projects which are not identified in this document? (1000 word maximum)

Several important international projects do exist (in for example neutrino physics and astronomy, cosmic ray astrophysics and dark matter detection) where the UK could contribute expertise and gain good value for money science return. However, community consultation has resulted in a clear identification of the three particle astrophysics projects which are all listed in Annex B6 of the consultation document, CTA, LZ and Advanced LIGO, as the priorities for the UK in the timeframe under consideration.

Two additional important, but lower priority, items have been identified:
1) an extension to the materials screening facility at Boulby that would support LZ activities, but also act as a resource for low background experiments in particle physics and particle astrophysics in the UK in the years to come.
2) capital support for the preparations for the L3 ESA slot (launch 2034), which will be a low-frequency gravitational wave mission.

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11. Should we maintain a proportion of unallocated capital funding to respond to emerging priorities in the second half of this decade? (1000 word maximum)

In general, Particle Astrophysics project lifetimes now extend beyond 10 years, which facilitates long-term planning and commitment of resources. It is therefore relevant to commit capital funding on those timescales. However it is important to hold some reserves back to support the funding of new opportunities that emerge within a long funding cycle. Not doing so could lead to a situation whereby new and important opportunities would be lost and the reliability of the UK scientific community brought into question simply due to the lack of available funding. It seems appropriate to retain of the order of 20% of the overall budget to react to such opportunities.

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12. Are the major international projects identified in the consultation the right priorities for this scale of investment at the international level? Are there other opportunities for UK involvement in major global collaborations? (1000 words maximum)

Particle Astrophysics is a broad discipline encompassing many different projects and lines of research. The major international projects in the UK programmatic review represent only a subset of those projects. However, those projects supported in the UK programmatic review document have been identified as having the highest priority from a UK perspective and are all high priority projects according to reviews from bodies such as ApPEC and ASPERA which represent the views of scientists and funding bodies across Europe. It should be stressed that global projects being supported in the UK represent the research interests of the UK Particle Astrophysics community.