Report from the Far Universe Advisory Panel

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http://research.icg.port.ac.uk/wikis/fuap

This document is split into two main parts. The first is a summary of the recent FUAP consultation and prioritization activity. The second part directly addresses the guidance requested by PPAN. We also provide two appendices that summarize two of the three community consultations we undertook since March 2009.

Executive Summary

FUAP is responsible for providing advice on the scientific health of the extra-galactic astronomy community. Over the last six months, FUAP in consultation with the public and other panels (NUAP/PAAP) has developed four major Science Themes (*Cosmology, First Light, Galaxies, Extreme Astrophysics*), which have 16 associated and ranked key science questions to be addressed in the coming decade. These themes and questions form the basis for a long-term science roadmap for STFC and should form the foundation for funding decisions on present and future projects. We also started the process of identifying important facilities that address these science questions and provide herein an initial table of key facilities for extra-galactic astronomy and cosmology. We have also identified four critical priorities for PPAN and STFC, which are *(1)* the support of young researchers via grants, studentships and fellowships, *(2)* the need for theoretical research and modeling, *(3)* the increased leverage of subscriptions to ESA and ESO, and *(4)* the importance of supporting innovative technology projects. We provide a brief response to the Ground-Based Facilities Review (GBFR) report and highlight complementary advice between these two reports. We stress that this report is the beginning of our advice to PPAN and we plan to revisit these issues in the future.

Part A: Consultation and Prioritization

The Far Universe Advisory Panel (FUAP) is one of five advisory panels to PPAN. The official tasks of FUAP can be found on the main PPAN webpage[1], which we have broadly interpreted as providing STFC and PPAN with:

- **A long-term science roadmap** for the extragalactic community. This will inform PPAN and STFC of the far universe science priorities for the coming decade.

- **A positive and forward looking statement** on the facilities, projects and experiments needed both today, and in the future, to achieve the science roadmap, and maintain UK leadership in strategic areas and to facilitate knowledge exchange and outreach activities.

- **A broad view** of the UK science productivity, which should include all aspects of a successful and healthy UK astronomical community.

The science remit of FUAP covers "*parts of the astronomy and space science programme concerned with the global properties of our galaxy, with objects beyond our galaxy, and with cosmology*." For further, and up-to-date, information on FUAP, please consult our webpage (http://research.icg.port.ac.uk/wikis/fuap).

Consultation

Over the last six months, FUAP has undertaken several consultations with the extragalactic community. The first was June 2009, where we requested feedback, via a web-based form, on our initial science strategy document. Overall, we received 98 submissions regarding this initial science document and have iterated both the content and style of our science themes in response to this consultation. In Appendix A of this document, we provide a detailed overview of this feedback and our responses to it.

On September 14th, we held a community town meeting at the Dept. of Physics and Astronomy at the University of Leicester, and in total approximately 50 scientists from most UK institutions involved in far universe science were present. At this meeting we discussed our final science strategy and presented our preliminary spreadsheet of key facilities. We received significant verbal feedback at this meeting (both positive and negative) and have attempted to capture this feedback in Appendix B.

We also provided a web-based feedback form for people at the meeting, and beyond, to comment on our final science document and the facilities spreadsheet. This web-based form was advertised to key people in the community and all the heads of departments/groups in the UK. By September 21st, we had received in excess of 60 contributions (within a single week) from across the FUAP community. We have used this extensive feedback to shape our advice in Part B of this document, and thank the

[1] http://www.scitech.ac.uk/About/Strat/Council/AdCom/tor.aspx

community for their comments, and we will continue to seek community input in the future.

After the September 28th meeting with PPAN, we published a previous version of this report on the FUAP webpage (we also published our presentation to PPAN from September 28th). We then emailed all 155 scientists involved in previous FUAP consultations (via our web-forms or who attended our September 14th town meeting) and invited further comment on this report (with a deadline of October 8th). We received some additional comments and have implemented some of them in this final version of the report.

During the drafting of our science strategy, we have consulted with other STFC advisory panels and reviews. In particular, we have worked closely with NUAP[2] and PAAP[3] regarding possible overlap of various science areas, and coordinated with the Ground Based Facilities Review[4] (GBFR). At the end of this report, we provide a brief response to the draft GBFR report and outline areas of common advice. We will continue to undertake such coordination through common membership, joint phone conferences and shared membership of email lists.

Prioritization

We provide in Part B four key science themes for extragalactic astronomy and astrophysics in the coming decade. With each theme, we provide the critical questions that need to be addressed written in language that should be understandable to a majority of people. The associated text within each theme is designed to be more detailed and at a level understandable by professional scientists. We have iterated these themes based on our consultations with NUAP/PAAP and the community.

In drafting these themes, questions, and text, we were strategic in selecting areas of astronomy and astrophysics that will be key areas of international research with strong UK leadership (or areas where we believe there should have strong UK leadership). This list is not meant to be an exhaustive description of all the extragalactic science UK scientists are engaged in, but represent the key areas of astronomy and astrophysics the UK should be involved in.

We also provide a broad prioritization of the critical science questions within each theme. Each question is classified into one of three possible bands, namely A, B and C (with "A" having the highest merit). This ranking was done internally to the FUAP panel, partly in response to the public feedback we received, which encouraged us to provide some level of prioritization of these science areas, and partly in response to the needs of PPAN in these difficult financial times. The ranking was based on a combination of science excitement behind each question, and a judgment of the UK's reputation and leadership in the area of research. Therefore, an "A" ranked question is seen to be an

[2] http://www.scitech.ac.uk/about/strat/council/adcom/NUAP.aspx

[3] https://paap.astro.cf.ac.uk/doku.php

[4] http://www.scitech.ac.uk/About/Strat/Council/AdCom/oth/GBFR.aspx

area which excels in all of these three criteria, i.e., it is scientifically compelling with world-leading past, present and future UK leadership in that area. Lower ranked questions were judged not to possess a similar level of excitement and/or leadership and reputation. We have not attempted to rank the four science themes amongst each other, which was supported by our public consultation.

We appreciate that our vision can be seen as too conventional and narrowly focused on areas of astronomy where likely returns on any investment can be guaranteed and quantified. We accept the public's feedback that astronomy should also embrace the "unknown and unexpected" as such endeavors have a rich history of making key astronomical discoveries. This also includes multi-disciplinary research where the outcomes often appear diluted at the start, but in reality can lead to major breakthroughs in science via sharing knowledge and resources. We therefore endorse the view that part of the wonder of science is exploring new domains that have no clear payback at the beginning, and believe some of our critical priorities and key facilities given below address this issue, e.g. fellowships and the need to support innovative technologies. This is also satisfied by new facilities, which explore new domains in wavelength, resolution, and/or time, which usually result in the discovery of new phenomenon.

Part B: Guidance

Astronomy, astrophysics and cosmology remain exciting and diverse areas of science. In the last decade, these research fields have made several major discoveries which have challenged our fundamental understand of the Universe and the physical laws that govern it. For example, cosmologists have discovered an accelerating universe likely driven by "dark energy" (or a misunderstanding of how gravity works on large scales). Likewise, the discovery of the "Gunn-Peterson Effect" from observations of distant quasars demonstrate that the Universe was re-ionized at some point in the past (confirmed recently by observations of the Cosmic Microwave Background). Nearer to home, the detection and mapping of tidal streams of stars around our Galaxy demonstrates the importance of galactic interactions in the build-up of galaxies in general, and tests our paradigm of hierarchical galaxy evolution. Finally, the recent discovery of compact (~one kiloparsec in size) massive galaxies at high redshift (z~2) further demonstrates that extragalactic astronomy has many surprises for us in the future, which will challenge our view of the Universe

The UK continues to lead in cosmology and extragalactic astronomy, and UK scientists are involved in each of the major discoveries discussed above. For example, UK theorists (e.g., the Durham and Cambridge groups) and UK surveys (e.g., 2dFGRS) feature extensively in the top 100 cited astrophysics papers[5] this decade (since 2000). This reputation and leadership should be maintained and encouraged in the coming decade, and emphasizes the importance of supporting people, at all levels, in exploiting the key facilities available to them.

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[5] Selected using the Astrophysics Data System (ADS). All the top 100 cited papers have >500 citations.

Future Opportunities

As requested by PPAN, we provide below an overview of the major scientific challenges to be solved in the future. Where appropriate, we highlight the UK involvement in research in these areas including what the UK reputation is in each of these subjects. In total, we focus on four key research themes with associated ranked critical science questions, and descriptive text to explain the excitement and likely future discoveries within these themes/questions, and the UK involvement in each. Three of the science themes are well established with important UK leadership and involvement. The fourth ("First Light") is an area of significant future science potential and therefore, we include this theme in our science strategy and encourage STFC support of this emerging area. The prioritization of the science questions have been outlined above.

We do not supply here information on the "Matching Current Programme to Roadmap Priorities" (despite it being requested in the guidance notes). This is because we have not had enough time or information (budgets, schedules, etc.) to address such complex issues and feel the present GBFR have already done an excellent job in this area (i.e., prioritizing a subset ground-based facilities out to ~2012). We therefore focus on the long-term view of science and associated facilities, and shall be happy to revisit this issue later with more time and access to the necessary information.

Science Themes and Questions

Rank	Cosmology
A	What is the nature of the dark matter and dark energy? *(c1)*
B	What are the physical laws that govern the beginning of the Universe? *(c2)*
B	Are the correct laws of physics and assumptions used when calculating cosmological evolution? *(c3)*
B	What is the origin of large-scale structures in the Universe? *(c4)*

In the past decade, a standard model of cosmology has emerged consisting of a nearly flat universe described by general relativity, with 4% of the energy in the form of ordinary baryonic matter, 21% in "dark matter", and the remaining 75% in some form of "dark energy" thought to be responsible for the present accelerated expansion of the Universe. Galaxies and large-scale structures are assumed to have grown gravitationally from primordial seed perturbations, possibly generated during a period of inflation in the early Universe.

However, there remain many unanswered questions with this model. For example, the origin of the primordial perturbations depends critically on the uncertain physics of the early Universe. Within the context of inflation, the scale dependence of the primordial density perturbations, the extent to which they obey Gaussian statistics, and the amplitude of any primordial background of gravitational waves will be key observational tests for discriminating between models. Moreover, recent progress towards realising inflation in fundamental (e.g. string) theory suggests a richer phenomenology than the simplest models, including large non-Gaussianity, cosmic superstrings, isocurvature modes and primordial magnetic fields. The most direct constraints on the primordial

perturbations come from the cosmic microwave background (CMB), but observations of galaxy clustering, weak gravitational lensing, the clumping of the inter-galactic medium, as traced by HI, and the abundance of galaxy clusters will play an important role in constraining the scale dependence and Gaussianity of the primordial perturbations on smaller scales than the CMB. [Questions c2, c4]

Cosmologists also need to tackle the conundrum of the "dark universe", which now includes two mysterious ingredients: dark matter and dark energy that dominate the energy budget of the universe. The basic properties of the dark matter, including its temperature and cross-section, can be probed astronomically by a range of cosmological observations, detailed investigations of the structure and dynamics of the local group, and searches for dark matter annihilation products. In addition, observations of the small-scale clustering of matter provides a promising route to measuring the absolute masses of neutrinos. Dark energy can be quantified using both the expansion rate of the universe, via geometrical tests from galaxy clustering and supernovae, and its impact on the growth of large-scale structures in the universe, probed using weak gravitational lensing, and galaxy and cluster surveys. The future of dark energy research is the combination of all these probes allowing cosmologists to test the underlying fundamental assumptions of the standard cosmological model (e.g. general relativity), and isolating them from systematic uncertainties in the observations. . [Questions c1, c3]

It is likely that large surveys of the Universe will continue to drive cosmology in the coming decades. The UK has a rich history in this field (e.g. APM, 2dFGRS, UKIDSS/VISTA), and should continue to play a leading role in forthcoming international CMB, radio, optical and infrared imaging and spectroscopic surveys. These cosmological surveys also provide invaluable statistical information on the properties of galaxies, providing synergy with the Galaxies theme below. Finally, the UK has underpinned this work with world-leading theoretical expertise and it is essential to maintain this if we are to capitalise on the scientific potential of our observational programmes.

Rank	First Light
A	How and when did the first stars, black holes and galaxies in the Universe form? *(f1)*
B	How and when did the Universe become re-ionized? *(f2)*
C	What are the best ways to find these first objects in the Universe? *(f3)*
C	How and when did the Universe become enriched with all the complex elements we see today in galaxies? *(f4)*

Observing and understanding the cosmic "dark ages", before the first objects lit up, is a long-standing problem in astronomy. This is the least studied and understood phase of cosmic evolution and should be a major goal of UK astronomy in the coming decades. A key issue is the formation of the first stars, which were likely massive objects, with short lifetimes, that rapidly enriched the surrounding gas which later forms into newer stars.

Observationally, this must have happened by z~7 as we can observe massive galaxies at this redshift with stellar masses at least a billion times the mass of our Sun. [Question f1]

To look beyond z~7, astronomers will need new techniques and instruments since these first objects will have faint fluxes. There are solid theoretical reasons to believe that the first stars may end as supernovae, and/or gamma-ray bursts, suggesting variability searches would be fruitful in finding them. It is also possible that other wavelengths, such as X-rays from early accreting black holes, may lead to the detection of the first objects. [Question f3]

Beyond the study of the first objects, we know that at z>5 the neutral hydrogen made at recombination (z~1100) became ionized again at some point. This must have occurred as a result of the formation of the first light emitting objects, and therefore the study of this "Epoch of Re-ionization" will be a major effort over the next decade. How and when this transition in the Universe occurred is still open for debate, but based on observations of the Gunn-Peterson effect, and results from the Wilkinson Microwave Anisotropy Probe (WMAP), our best estimate is z~10, which redshifts the 21cm hydrogen line into the megahertz (radio) regime of the electromagnetic spectrum. New experiments are already underway to probe this new frontier, with more on the horizon. [Question f2]

Today, we witness that the Universe is thoroughly enriched by heavy elements, most of which were probably produced through stellar evolution processes. The details of how the Universe became enriched is an important question for astrophysicists, and based on elemental abundances in high redshift quasars (and damped Lyman-alpha systems), it is clear that this enrichment occurred rapidly at an early epoch, probably via a feedback mechanism related to the evolution of first stars and black holes (e.g., stellar winds, and supernovae). Therefore, a combination of observational (e.g., absorption line studies and direct measurements of abundances within galaxies through spectroscopy) and theoretical simulations is required to trace the entire chemical enrichment history of the Universe from the start until today. [Question f4]

The UK has been one of the leading places for studying the earliest galaxies thus far discovered, and it will be important in the coming decades to expand this to the first objects to form in the Universe, and measurements of the epoch at, and before, re-ionization.

Rank	Galaxies
A	How do galaxies form and evolve? *(g1)*
B	What is the role of environment and interactions in galaxy evolution? *(g2)*
B	What are the contents of galaxies and their internal structures and mechanisms? *(g3)*
C	What lies between the galaxies? *(g4)*

Rapid advances in observational astronomy are starting to reveal an intricate picture for how galaxies formed and have evolved. Moreover, numerical simulations have become increasingly sophisticated in modeling how structures emerge in a cosmology dominated by dark matter and dark energy. However, many fundamental problems remain unsolved due to the large dynamic ranges in scale and mass involved in such research, and the complexity of the astrophysical processes involved (e.g. star formation, mergers, feedback from supernovae and active galactic nuclei). [Question g1]

In the next two decades, new radio, optical, X-ray and gravitational wave facilities will be used to study galaxy formation, by probing the Universe to an unprecedented depth in time and mass using many complementary techniques and wavelengths. New insights will also be gained into how stars, dark matter, central massive black holes, cosmic magnetic fields and, increasingly, the neutral and cold gas evolve in galaxies as a function of time. Astronomers will also probe the internal kinematics of stars and gas in galaxies to high redshift using the next generation of radio and X-ray telescopes, as well as extremely large optical telescopes and integral-field spectrographs. In parallel, wide-field surveys of the Universe will statistically map the distributions of galaxy properties as a function of environment, which will provide an insight into the role of energy feedback and chemical enrichment to explain the inter-galactic medium. It will also help determine the importance of mergers and interactions in shaping the properties of galaxies. [Questions g2, g3, g4]

Nearer home, the global properties (including the kinematics, substructure and the central massive black hole) of our own Galaxy will be studied with both ground-based facilities and space satellites. The dynamics and chemical composition of billions of stars in our Galaxy, and other nearby galaxies in the Local Group, will be used to untangle the formation history of these individual objects, thus allowing scientists to test and challenge directly cosmological galaxy formation simulations on sub-galactic scales. [Questions g1, g2, g3]

The UK is leading the world in the interplay between the observational and theoretical study of galaxies. We should invest in this area to maintain our reputation and involvement in the next generation of observational facilities and high performance computing (HPC).

Rank	Extreme Astrophysics
A	What are the sources of gravitational waves? *(e1)*
B	Do the known laws of physics on Earth apply under extreme conditions in the Universe? *(e2)*
B	What is the astrophysics behind accretion of matter and energetic feedback around compact objects? *(e3)*
C	How and where does relativistic particle acceleration occur? *(e4)*

One of the most fundamental questions we can ask is whether our laws of physics work under the most extreme physical conditions. The Universe is the most natural laboratory available to scientists for such tests, as it provides extreme ranges of gravity, density,

temperature, magnetic field and radiation. By observing these regimes across the entire electromagnetic spectrum, and via gravitational waves, cosmic rays, and neutrinos, we can, by comparison with detailed theoretical models, provide the strongest possible test of our understanding of astrophysics. [Question e2]

The behavior of light and matter close to a neutron star or black hole probes the strong-field regime of general relativity where the effects of light bending and "frame drag" are maximal. The coupled processes of accretion and outflow, whether radiatively or magnetically driven, link accreting objects to their surroundings via a feedback mechanism. This is the route by which massive black holes grow across cosmic time, changing the black hole mass and spin. Outflows from the centers of galaxies combined with those from star-forming regions result in large amounts of energy being deposited into the host galaxy and beyond helping to drive star formation, regulate galaxy evolution, and heat the ambient medium. [Questions e2, e3]

The observation of gravitational waves (and/or neutrinos) will provide unique insights into the formation and evolution of systems such as binary mergers and core-collapse supernovae. Extreme environments are also prime sites for relativistic particle acceleration, often resulting in intense non-thermal radiation from phenomena such as pulsars, gamma-ray bursts and giant radio galaxies. [Question e1, e3, e4]

The UK has an excellent track record in this area, both in constructing and exploiting facilities that make use of naturally occurring cosmic environments in our Galaxy, and beyond, to test the laws of physics. Extreme astrophysics is an area where we can learn much by comparing the properties of stellar-mass scale objects in the local Universe to massive objects in the distant Universe. To ensure continued UK leadership in this research, astronomers need a multi-wavelength view of the Universe, with high-resolution observations in time, frequency and space.

Important Facilities

As requested by PPAN, we now identify the critical facilities and top priorities for the extra-galactic community needed to reach the goals outlined above. At the top of our (green) spreadsheet given below we have identified four ranked critical priorities for the health of the Far Universe community. The FUAP panel members determined the rankings of these priorities with input from the community. These priorities span all aspects of FUAP research, and we strongly recommend should be protected and supported.

The facilities listed in the spreadsheet are not ranked. However, these facilities represent the top priorities for the four research areas, and were selected by the FUAP members (with much feedback from the community), with emphasis on the ranked science questions given above. (We provide a broad mapping of these science questions to facilities in the spreadsheet). We have attempted to provide guidance on near-term facilities (in the next five years) and long-term priorities (over the next two decades). We make no comment on the cost and/or timing of these facilities, as FUAP did not have access to this information, nor the time to develop a detailed cost/benefit analysis. We have focused solely on the science potential using information in the public domain and do not comment on detailed strategic issues associated with these facilities.

We stress that there are many important facilities not listed and we debated the inclusion of a second tier of facilities in our spreadsheet. Based on public feedback at the Leicester Town Meeting (Sept 14th 2009), we decided not to provide this second tier at this time, but wish to emphasise that the facilities presented in this spreadsheet represents the *"Crown Jewels"* of the extragalactic research programme and are vital to addressing our key science questions. There are other facilities that complement those listed in the spreadsheet, by strengthening and extending the research capacity of UK scientists, and we hope PPAN does not use this spreadsheet alone in making important funding decisions. The GBFR has given a more detailed overview of smaller, and more near-term, subset of UK facilities and we would point the reader to their report for guidance on individual rankings of specific existing facilities (also see our response to the GBFR below).

Finally, in the spreadsheet below, we have provided a mixture of named facilities (like Planck, HST), while in other cases, only highlighting important capabilities, e.g., wide-field spectroscopic survey. At this time, we only felt able to name specific facilities in our spreadsheet if they provided a unique science capability and/or were vital to UK strategic interests. Beyond this, we felt uncomfortable naming specific projects if there was a competition between various facilities to deliver the same science and/or capability. We would like to delay any specific recommendations in such cases until we have the appropriate information in front of us (e.g., budgets, schedules, etc.). Also, where appropriate, we have been purposefully agnostic about the size of facility/telescope in the hope that smaller telescopes/experiments can also be seen to deliver the key capabilities we highlight. Again, we are happy to revisit these issues with more time and information, but in the meantime, would direct PPAN to the GBFR for a more detailed analysis of a sub-set of (ground-based) facilities (see below).

FUAP Facilities Spreadsheet

Science themes and critical priorities	Now (next 5 years)	Future (next 20 years)
Critical Priorities	1. Protect funding for people (grants, studentships, fellowships) to continue in the preparation and exploitation of data from facilities. 2. Maintain healthy funding for theoretical research including simulations (access to HPC) and modeling. 3. Leverage our subscriptions to ESA/ESO by improving our exploitation and involvement in these key facilities. 4. Maintain technological capacity in UK groups by investing in small-to-medium size astronomy projects, thus allowing people to be innovative and respond quickly.	
Cosmology	• Wide-area weak lensing (WL) survey (c1, c3, c4) • Wide-area galaxy spectroscopic survey (c1, c3, c4) • Planck (c1, c2, c3, c4) • Ground-based CMB polarization experiment (c1, c2, c4)	• Next generation wide-field WL survey (c1, c3, c4) • Next generation wide-field redshift survey (c1, c3, c4)
First Light	• 8-metre telescopes (f1, f4) • LOFAR EoR (f2)	• 8-m class optical telescopes and ELT (f1, f4) • JWST (f1) • SKA (f1, f2)
Galaxies	• HST and 8m optical telescopes (g1, g2, g3, g4) • SCUBA-2 (g1, g3) • GAIA (g1, g2) • Herschel (g1, g2, g3) • e-MERLIN (g1, g2, g3)	• JWST (g1, g3, g4) • 8-m class optical telescopes and ELT (g1, g2, g3, g4) • ALMA (g1, g3) • SKA (g1, g2, g3, g4)
Extreme Astrophysics	• LOFAR Transients (e3, e4) • XMM-Newton (e2, e3, e4) • Transient surveys and rapid large telescope follow-up in both hemispheres (e1, e3) • Advanced LIGO (e1, e2)	• IXO (e2, e3, e4) • LISA (e1, e2) • SKA (e1, e2, e3, e4) • Access to large (8-m and ELT) optical telescope in both hemispheres for follow-up (e1, e3)

Explanation of Facilities Spreadsheet

We provide here a commentary for the (green) "facilities spreadsheet" provided above. We focus here on explaining why certain facilities were included, rather than debating missing facilities.

Critical priorities beyond facilities: At the top of the spreadsheet, we provide critical priorities that cut across all facilities and are essential for a healthy community. These priorities are not ranked above the facilities (in the rest of the spreadsheet), but simply placed at the top to highlight them. We hope PPAN will recognize them as key recommendations from this report.

- FUAP, and much of our community, believe it is essential to protect and enhance the support for young researchers in our universities and laboratories. The access to such talent to exploit the UK facilities is crucial. Moreover, the fellowship programme (especially Advanced Fellowships) allows the best people to explore the unknown and search for unexpected phenomena, which, as we stated above, is an important mode of research in astronomy. We believe further cuts to the grants and fellowships programmes would be detrimental to the health of UK astronomy, and urge STFC to reverse recent trends, which have seen several cycles of deep cuts to grants and fellowships.

- We support the importance of theory, interpretation and modeling of data (including access to high performance computing). This is clearly an area of UK research excellence, and such theoretical work is key to supporting facilities by providing insight and guidance on the expected and/or best observational programme to test the underlying physical phenomena. Theory is relatively cheap to fund, but is easily forgotten when tough funding decisions are made.

- It is clear that a majority of STFC astronomy funding goes towards international subscriptions to ESA and ESO. These astronomical institutions provide major resources and facilities to UK astronomers (e.g., VLTs, VISTA, ALMA, future opportunities through ESA's Cosmic Vision, Herschel/Planck, XMM, HST, JWST, etc.). We feel that STFC should do more to encourage UK astronomers to maximize the exploitation of these facilities (e.g., providing targeted funding to achieve that goal and/or collate paper and proposal statistics on UK usage of facilities). STFC should also be more proactive in helping the UK research community become more involved in the management and governance of these large facilities, and provide more stable support of associated projects to build instruments, data archives and lead the science from these facilities.

- FUAP is concerned about the health of technology research groups within the UK. We believe the UK research community has a rich history of innovative thinking and novel technological solutions to science problems. We urge STFC to protect these technology groups and suggest the establishment of specific funding to support small-to-medium size initiatives in the universities and labs (this does not mean moving all such expertise to Harwell!). We are deliberately non-specific here about our definition of technology projects as we see this as including telescope instrumentation, data storage and archiving, software development and internet-based solutions.

Key Facilities: We present here the very best research facilities needed to deliver the key science themes and questions above. Where appropriate, we have mapped the science questions in the above tables to the facilities to help illustrate how these facilities were chosen, e.g., for "first light" we reference question f2 for "LOFAR EoR". Again, our selection of facilities was decided based on research excellence, UK leadership and reputation. We have not included international research facilities that are currently freely available to UK astronomers. The facilities in our spreadsheet are the ones that STFC has a financial obligation to supporting or are actively considering. Finally, as discussed above, we only name specific facilities, which we feel deliver a unique science capability and/or have key UK strategic importance. In other cases where multiple facilities may deliver the same capability, we simply highlight the importance of the science capability that is needed to address the science questions.

Cosmology

- Access to high-resolution imaging and spectroscopic surveys is key to mapping the dark universe (matter and energy) and the UK has world-leading expertise in this area. These two techniques provide the best opportunity to understand dark energy and/or modified gravity, while access to multiple methods safeguards against systematic uncertainties. It is essential for the UK to play a leading role in future dark universe surveys as they become larger and more international.
- The CMB (imaged with Planck and ground-based experiments) remains the cleanest probe of the early Universe and the initial conditions for structure formation. UK instrumentation and theory groups have been involved in major CMB experiments for many years and we recommend this continues with a ground-based programme potentially leading to a significant role in a post-Planck satellite optimised for polarization

First Light

- FUAP believes access to instruments that probe the epoch of re-ionization are vital for this science theme. LOFAR and SKA have critical UK involvement and leadership.
- JWST and large optical telescopes (8-metre telescopes and larger, especially the ELT) provide facilities to see the first objects formed in the Universe. This is an area for huge discovery potential in the future.

Galaxies

- We emphasise the continuing role of 8-metre telescopes in providing images and spectra of high redshift objects, especially those associated with a number of well-studied deep fields scattered across the sky. The goal here should be to increase the multiplex instrumentation of these telescopes (imaging and spectra) to improve the statistical samples available to researchers.
- GAIA is a unique project that the UK has essential involvement in. We expect UK groups to make key use of this satellite data in the coming years in understanding the chemical and dynamical history of our Galaxy.
- FUAP believes that SCUBA-2 and Herschel are UK niche facilities that provide insight into the dusty universe at high redshift. Both have UK leadership and the surveys from both will provide UK scientists with a competitive advantage over the rest of the world.
- e-MERLIN is a UK-led project which will deliver high resolution radio

images of galaxies to high redshift. Such resolution will provide a new window on the morphologies of galaxies thus advancing studies of AGNs, star-formation and gravitational lensing.

- In the future, the major facilities of ALMA, ELT, SKA and JWST will also be vital to probing galaxy evolution to high redshift and across the electromagnetic spectrum. The diversity of data collected by these instruments will together help unravel the complex astrophysics driving galaxy evolution.

Extreme Astrophysics

- Astronomers are just beginning to explore the transient universe at all wavelengths. We must continue to support this field by providing access to the time-varying sky and access to large telescopes for follow-up of discovered sources. Access is required in both hemispheres to facilitate all-sky coverage.
- XMM-Newton remains an excellent satellite, which is great value for money. FUAP endorses ESA's desire to continue with this mission and recommend STFC will continue funding data exploitation of this facility. It has unique ability to provide timing data and deep spectroscopy over large areas of the X-ray sky. The future of X-ray astronomy lies with IXO and we support the UK involvement, via ESA, in that mission.
- In the future, extreme physical phenomena will include the understanding of gravitational waves. FUAP supports continued work towards the detection of this radiation. Advanced LIGO is an obvious next step in this work and should be supported as a pre-cursor to a full space-based experiment. An intriguing and compelling complementary search for gravitational waves is via the SKA and LISA.

Relationship to the GBFR Report

The Ground-Based Facilities Review (GBFR) has recently released its draft report for community consultation and we provide here a brief response to that report. We begin by noting that the remit of FUAP is both different, and broader, than that of the GBFR, e.g., FUAP includes space-based facilities, focuses just on the Far Universe community, and has looked at different aspects of the scientific productivity of this community. That said, the GBFR has undertaken a much deeper, and more quantitative, consultation with the community, on a number of ground-based optical, infra-red and radio facilities that are important to the FUAP community (although it was not tasked to look at ground-based CMB and gravitational wave experiments which are important to some of the FUAP science questions above). Therefore, we feel it is important and helpful to provide PPAN with a brief summary of how we (FUAP) view the appropriate (ground-based) components of our advice compare to the GBFR advice. We stress that the two panels have worked in parallel, with some correspondence and coordination (with joint membership of Rob Fender), but on a whole, the GBFR advice is independent of FUAP.

We begin by revisiting the table of priorities given in Section 4 of the draft GBFR report. We reproduce their table below and colour in red items we feel have significant agreement between the two sets of advice. We also provide explanatory notes below the table. Items that are not coloured in the table below correspond to items that are either

outside the remit of FUAP and/or have not been covered in our preliminary advice summarized in our spreadsheet above. We caution against assuming these are unimportant facilities to FUAP and recommend PPAN considers the GBFR report on these facilities.

Table 4 from the draft GBFR report (Early October)

	High Cost (>£5M/yr)	Medium Cost (£1-4M/yr)	Low Cost (<£1M/yr)
Very High Priority	ESO subscription SKA, E-ELT	ELT instruments	
High Priority		N.Hemisphere 8m JCMT to 2014 WFMOS on Subaru e-Merlin to 2014 UKIRT (if UPF) to 2014 LSST (UK Role)	WHT until 2017 LOFAR running costs SuperWASP to 2012 Wide Field units ALMA Regional Centre MROI CCAT
Medium Priority	25% share in Gemini	wfMOS on WHT	MROI beam-combnr
Good science but lower priority		Gemini Support	JIVE, INT, LT

i) *The very high priority for the ESO subscription is complementary to our third critical priority "to leverage ESO/ESA subscriptions" in our facilities spreadsheet above.*
ii) *The ability for UK groups to participate in ELT instruments is again in agreement with our critical priority "to leverage ESO/ESA subscriptions"*
iii) *SKA and ELT are equally represented in our facilities spreadsheet and clearly important to many of the FUAP science questions.*
iv) *Under Extreme Astrophysics, we stress the need for access to large telescopes in both hemispheres for rapid transient follow-up.*
v) *Under the Galaxies theme, we highlight both e-MERLIN and JCMT as niche UK facilities for studying the dusty, high redshift Universe.*
vi) *Both WFMOS and LSST are two examples of the next generation cosmology survey instruments/facilities that should deliver the required lensing and redshift data discussed herein under the Cosmology theme. However, we should note that there are other space missions and UK/ESO experiments that could also deliver this data and for this reason, FUAP did not name specific facilities in our spreadsheet above. As stated before, we would encourage PPAN to leverage our existing ESO/ESA subscriptions where possible.*
vii) *LOFAR is featured in both the Extreme Astrophysics and Fight Light themes.*
viii) *"Wide Field units" is one example of UK technology groups that require support as outlined in our fourth critical priority in our facilities spreadsheet.*
ix) *The ALMA regional center is an example of our advice to "leverage ESO/ESA subscriptions" to provide UK scientists with the science support to exploit new ESO facilities like ALMA.*
x) *Support of Gemini is consistent with our required need for access to 8m-class telescopes as presented in the Galaxies and First Light themes in our facilities spreadsheet.*
xi) *wfMOS on WHT is another possibility for future wide-field spectroscopy under the Cosmology theme, although again we would suggest PPAN leverages our ESO/ESA subscriptions where possible.*

In addition to this table, the GBFR report also makes the following two recommendations (taken from their executive summary), which directly overlap with the FUAP critical priorities outlined in this report, thus strengthening this advice to PPAN. These are:

- "*The Panel attached great importance to a continued UK role in the development of, and provision of, state-of-the-art instrumentation for ground-based telescopes. This is important for knowledge transfer and investment in the technologies of the future, as well as giving scientific leadership to the groups involved."*

- *"The Panel took the view that the university Grants line is of very high priority for the future of ground-based astronomy, both for exploitation of our facilities investments and for independent theoretical work that paves the way to new observational ideas."*

We recommend that PPAN consider the entire GBFR report as we only provide here a brief overview of the complementary parts of our two reports. We broadly endorse the findings of the GBFR where it impacts on the Far Universe community. We believe that together, the GBFR and FUAP reports provide PPAN with a consistent picture of the science and facilities priorities for our community.

Appendix A: Report on public feedback on the initial FUAP Science Strategy Document.

This information is provided to PPAN to provide context and demonstrate how we considered and responded to the community feedback. We have implemented the changes discussed in the text below.

We present here a brief overview of the comments we received on our initial FUAP Science Strategy document. We collected these comments via a web-based public consultation during June/July 2009. In total, we received 98 submissions and provide a summary of these submissions below. Where appropriate, we provide a brief reply to some of the most common and/or important comments (given in italics).

General Comments

We provide here a summary of general comments made by the community on the structure of our initial document, and the FUAP approach in general. Again, we provide some replies (in italics) where appropriate.

- Overall, most people appeared happy with our present approach. Specific supportive comments included agreement that it was best to define the important UK science questions first and then prioritize the facilities. It was re-assuring to the community that the panel was composed of younger astronomers, and people saw synergy with other reports (which is encouraging).

- Several people were concerned about the broadness of the science themes, with no apparent prioritization. Therefore, the science strategy could become useless as it does not inform decisions on funding and facilities.

  FUAP agreed with this criticism and have now implemented a science prioritization of the key questions in each theme. However, we decided not to rank the four science themes themselves, as this seemed impossible to agree on. We considered using publication/citation statistics to guide us in the prioritization, but a preliminary investigation of such methods convinced us that this was fraught with difficulty, especially when dealing with different sized communities and groups in cosmology and extra-galactic astronomy. Also, such methods are biased against emerging areas of research e.g., "First Light" in our document. In the end, we individually ranked all the science questions using our best judgment for the present and future excitement of each research question, and the UK's reputation and leadership in the associated area of research. We then averaged these rankings to provide the basis for one of three possible priorities (A ,B or C; with A being the highest). Overall, the agreement within the panel was remarkably good and we have used this science prioritization to better inform our prioritization of facilities and research priorities. We now provide the prioritization of the science question in the final FUAP Science Strategy document.

- Many people highlighted the need to plan for the unknown or unexpected. Many

worried that our document reflected the conventional wisdom and missed the wonder of astronomy in finding amazing new phenomena in the Cosmos. Also, people stressed the importance of multi-disciplinary science.

FUAP agreed with this sentiment and have added a statement to this effect in the revised document. However, beyond highlighting this issue, it is unclear how one can plan for the unexpected and prioritize it against the clearer objectives of other (conventional) areas.

- Overlap with other panels and the fear of science areas falling between the cracks, e.g., extreme objects (X-ray binaries, SNe, etc.) both in our Galaxy and in distant galaxies, structures in our Galaxy and the (very) local dwarf galaxy population, importance of stellar astronomy to both far and near universe, gravitational wave astronomy, and particle astrophysics and CMB research.

  FUAP acknowledges this concern and is working to mitigate such problems. For example, NUAP and FUAP have since held a joint phone conference, and members of both panels are encouraged to exchange information. FUAP has also offered informal membership to all NUAP and PAAP members, with two NUAP members now participating regularly in the FUAP email list. We will continue to discuss with STFC the membership and structure of these panels, which could be changed in the long-term. We also encourage any concerned stakeholders to contact the appropriate panel chairs.

- Several people stressed the importance of theory and computational science. They stressed it had high international impact and was cost-effective. There is much fear that with cuts to STFC research spending, this area will be disproportionally affected.

  FUAP agrees with this assessment and shares the concerns expressed. This is clearly an area of significant UK leadership. We have stressed the importance of theoretical work (including simulations) in our Science Strategy document, and plan to directly address this issue when we discuss facilities.

- Several smaller, but important, comments included:
  i. More funding for young people to stay involved and use future facilities, *(FUAP will address this when prioritizing facilities)*
  ii. Attempts to measure the relative strengths of UK science areas (e.g. citation statistics), *(See comments above about the difficulty of using such metrics)*
  iii. Weigh all comments equally, from professors to graduate students *(FUAP weighted all comments equally)*
  iv. No need to always build new facilities. Existing ones can be put to good use,
  v. Outreach is important and can inspire young people,
  vi. In the harsh reality of the UK budget, economic impact must be stressed, as just performing good science is not enough.

Extreme Astrophysics

Overall there was broad support for Extreme Astrophysics as a theme and its importance among the UK research community. Several comments emphasised cross-theme research, multi-wavelength research, the importance of computational support and the need to maintain UK access to multi-wavelength facilities.

Some specific areas of concern are highlighted below:

- Overlap with NUAP and PAAP: Several comments were addressed at whether some topics would "fall between the cracks" among the various panels. Of particular concern were those Galactic sources, which emit high-energy radiation such as pulsars, X-ray binaries and the like. Example comments include:

  "While I am quite glad to see support for research on pulsars and X-ray binaries in this document, I think the formal remit for the panels indicates that the NUAP should be the one doing that."

  "As massive stars find themselves at the boundary between the Near and Far Universe, there might be a risk that both panels (Near and Far) assume the other panel will take care of it."

  "In your extreme astrophysics section, all of these questions (perhaps excluding gravitational waves) can be also asked within our galaxy."

  "I must admit to being slightly confused when I was informed by the powers that be that extreme physics in galactic sources should not be covered in the near universe panel, but in the far universe panel."

  "I think all four themes could give greater prominence to stellar astronomy and the need for continued work in stellar evolution."

- Suggestions for changes to questions: As expected, many responses were objections to particular questions or the emphasis (or not) given to some topics. Examples are given below and we have revisited the text appropriately if we felt there was merit.

  "I really don't believe the relativistic particle acceleration question is a key one for UK science - it's much more of a niche area."

  "We don't need to know what the sources are of gravitational waves and neutrinos, we need the answers to physics questions, and you need to identify what these physics questions are."

> *"Feedback is a hot topic, but the way the proposal handles this seems to presuppose that it is all down to AGN, so it's in 'Extreme Astrophysics'. In practice, a lot could be down to supernovae."*
>
> *"Cosmic magnetism is going to be a growing field of astrophysics in the next decade."*
>
> *"The only question that seems out of place is: "How and where does particle acceleration occur?" Although interesting, I feel that this is a detailed issue that could be subsumed into the second question of Extreme Astrophysics".*
>
> *"Supernovae are only mentioned with respect to gravitational waves. However there is major interest in the UK."*
>
> *"[Change the 1st question to] Can the known laws of physics explain the most extreme conditions and processes in the Universe?"*
>
> *"I would like to see the probes of fundamental physics using high energy observation of the Universe given perhaps more emphasis."*

- The importance of particular types of observation: Given that some decisions will have to be made as to the importance of particular facilities and observational strengths/weaknesses, some responses mentioned the need for access to a particular waveband or type of observation. These issues will be addressed in our prioritization of facilities, but we provide some examples below.

> *"TeV observations are becoming increasingly important. Unless we can study variability in detail we won't go far"*
>
> *"Detection of the energy scale of quantum gravity by ground and satellite based observations of GeV/TeV photon emission from distant GRBs and AGN is not implicitly mentioned and this should certainly be included."*
>
> *"GRBs offer a particular example where we benefit from multi-wavelength AND wide geographical coverage."*

- An Additional theme**:** Only one area was commented on as a possible extra theme, namely the detection of gravitational waves.

> *This was considered by the panel but rejected as it was felt the emphasis should be on the astrophysics rather than the detection method.*

Cosmology

Of the 97 web responses, 37 made specific comments on the Cosmology theme. Overall, most comments were generally positive, but specific issues are detailed below.

- Missed Science Questions: Most respondents were happy that we had covered the most important science questions. Suggestions for missing questions included

    - What is the physics of galaxy clusters?
    - Did primordial magnetic fields play a role in the origin of Galactic magnetism?
    - What are the masses of neutrinos?

    We consider the physics of galaxy clusters to belong in the Galaxies theme and is covered by the question "What is the role of environment and interactions in galaxy evolution?" and "What lies between the galaxies". We have added a reference to primordial magnetic fields to the sentence "Moreover, recent progress towards realising inflation in fundamental (e.g. string) theory suggests a richer phenomenology than the simplest models, including large non-Gaussianity, cosmic superstrings, and isocurvature modes" in the text, but also consider the role of primordial magnetic fields, in Galactic magnetism, to be covered by NUAP. Finally, our original document did mention the mass of neutrinos, but we have now added a sentence explicitly describing the role of observations of the small-scale clustering of matter in constraining absolute neutrino masses.

- *Techniques:* Several respondents stressed that some judgment on the relative strengths of various techniques should be made (for example, dark energy probes). We also received the following suggestions for techniques that should be worked into the text

    - Gamma-ray bursts as standard sirens for geometric tests,
    - Refining primary distance indicators for measurements of the expansion rate,
    - Gravitational wave emission as tests of General Relativity,
    - Peculiar velocity measurements (for example from Sunyaev-Zel'dovich observations of clusters) as tests of (modified) gravity,
    - Near-field cosmology (i.e. Local Group) as a probe of the properties of dark matter,
    - Gamma-rays from dark matter annihilation in our Galaxy as a probe of dark matter properties,
    - Detecting the energy scale of quantum gravity with GeV/TeV emission from Gamma-ray bursts and AGN,
    - CMB polarization for testing inflation and, via CMB lensing, for constraining neutrino masses and dark energy.

We have chose not to list all possible types of cosmological observations that could be used to constrain the nature of dark matter and dark energy. We have however highlighted the best techniques in our opinion (based on several recent dark energy reviews). We have expanded the text to include the important role that near-field cosmological observations can play in probing the properties of dark matter.

- Suggested changes to text: We received a few suggestions for improvements to the text.

  - Question 2: make this question about the structure in the CMB rather than large-scale structure since the latter follows from the former by "well understood" physics.

  - Question 4 is too imprecise -- it would be helpful to specify over what epochs the question is referring (e.g. Planck time, inflation, nucleosynthesis, z<1 etc.)

  - This theme would be better entitled "Origins" rather than "Cosmology".

  We consider structure in the CMB as a tool rather than an end in itself. The origin of structure can be probed both by the CMB and large-scale structure, using the "well-understood" physics to tie them together. We considered making question 4 more precise, to properly distinguish it from question 1. We changed it to "Are the correct laws of physics and assumptions used when calculating cosmological evolution?" We disagree that the theme would be better entitled "Origins" since origins is often taken to include the origin of life as well as the origin of the universe.

Galaxies

Comments regarding the "Galaxies" theme of our document were overall positive. A few issues were raised by multiple responses, and thus warrant particular attention.

- The Galaxy, GAIA, resolved stellar populations: A number of people commented on the importance of near-field cosmology, i.e., studying the global properties of the Galaxy (e.g. satellite streams), particularly with GAIA, and in the future, resolved stellar populations in nearby galaxies. The latter will become important when 30m class telescopes become available in the next decade. For example:

  "My main concern here is that you have downplayed that part of your remit which covers "the global properties of our galaxy". It seems clear that, thanks to GAIA, this will be one area of astrophysics which is almost bound to be revolutionised in the next 15 years, and it would be a great pity for the UK to miss out on that by not being adequately prepared.

  The upcoming GAIA (and other) mission will turn the Milky Way into the Rosetta stone for Galaxy evolution/formation/dynamics research. I feel that this should be explicitly emphasized in the science

questions/themes."

We accept this was not clear in the original document and have emphasized the role of such surveys in our understanding of galaxy formation and near-field cosmology.

- Star formation in the Galaxy and external galaxies: A number of responses remark on the importance of studying star formation in the Milky Way and nearby galaxies, which many fear may have fallen between the remits of NUAP and FUAP.

  "The importance of a better understanding of star formation in terms of galaxies and their structure should be emphasised.

  Depending upon how the boundaries of NUAP and FUAP evolve, some areas are lacking a natural `home'. These include differing modes of star formation (quiescent within Milky Way; violent within starburst galaxies and ULIRGs), stellar populations in external galaxies (e.g. dwarf galaxies/ clusters within halo of M31 of relevance to galaxy assembly), …"

  We are coordinating with NUAP on this issue to ensure it is not forgotten.

- Cosmic magnetism: A number of responses remark on the importance of cosmic magnetism in galaxy formation, and possibly in cosmology.

  "Cosmic magnetism is going to be a growing field of astrophysics in the next decade (e.g. Key Science Projects for LOFAR, ASKAP, SKA and increasing use of MHD numerical simulations) and the UK is very active.

  Although it was briefly mentioned at the end of one paragraph, I believe that in the next decades the emphasis of studies of the role of magnetic fields in high red-shift astrophysical objects and indeed in the primordial universe should be emphasized."

  We have already mentioned this science area in this theme and others, and feel it is represented appropriately in the text.

- Multi-wavelength approach: Several people commented on the importance of using a multi-wavelength approach to study galaxies and cosmology, from radio to the gamma-ray, including in time-domain astrophysics.

  "I would support a strategic plan that provides multi-wavelength imaging and spectroscopy from the ground in a coordinated way.

  I strongly endorse the need to maintain a flexible multi-wavelength approach. Much of the success of UK astronomy has been in its ability to move into new wavelength regimes as and when technology allows."

  This we feel is an issue of facilities rather than a science question. We think the text adequately reflects the science need for a diversity of observations in this theme,

and this will be reflected in the prioritization of facilities.

- Central massive black holes and supernovae/AGN feedback: A number of responses emphasized the importance of probing massive black holes in our own Galaxy and in external galaxies, as an integral part of understanding galaxy formation and evolution. Feedback from supernovae and AGNs should be stressed on equal footing. Gravitational waves can potentially be used to study mergers of massive black holes at the centres of galaxies.

  "You may want to explicitly mention the build-up/formation of the central super-massive black holes in galaxies.

  I also think that the role of the black hole in Galaxy evolution should be one of the main galaxy questions.

  Feedback is a hot topic, but the way the proposal handles this seems to presuppose that it is all down to AGN, so it's in "Extreme Astrophysics". In practice, a lot could be down to supernovae, so you should either make it clear that these are included under this heading (are they extreme enough?)."

First Light

Comments regard the First Light theme were overall positive, although not as numerous, in comparison, to the Cosmology or Galaxies themes. We provide a summary of comments and suggestions

- The chemical enrichment of the universe: We received most comments about this subject. Some thought that this should be in the Galaxies theme, which is a fair comment. Most of the comments on specific science questions related to this issue, with some people even mentioning that this is the most important part of the "first light". Others thought a more interesting question is how the chemical evolution history evolves with time, although this is better covered in the Galaxies theme. Some mentioned that "complex elements" is an ambiguous term that should be better defined.

- Question 1: Several people commented that another important question, independent of stars and AGN, is the initial formation of the first galaxies and indeed it is probably worth mentioning the first galaxies as well here in future lists of questions. While it is likely the case that the first AGN and stars were formed within galaxies, and thereby creating the first galaxies in the process, this is not definitely the case and the processes could be decoupled.

- Question 3: A number of people took issue with this question regarding techniques for finding the first objects in the universe. Those who mentioned this brought up the fact that this question is not like the others in that it is a technique question rather than a "hard" science question. It is worth pointing out that some people mentioned in the questionnaire that new techniques and ideas were not mentioned enough, so this is an example where addressing a technique is include in our list of problems/questions.

- Other ideas: Many respondents mentioned other techniques for studying the "first light" including Gamma-gamma absorption through extragalactic background light to study the first physical processes, as well as using statistical properties of the last scattering surface to determine properties of the first objects. The impression here is that we have determined the best ways to observationally study the first objects in the universe, while we have left this open as a separate question.

- Comments on 21cm science: A few people stressed that 21cm science will be a major focus of 21st century astronomy. It is possible that our question about studying the re-ionization implies 21cm observations quite strongly to those interested in this area.

Appendix B: Minutes from the FUAP Town Meeting on Sept 14th at the University of Leicester

Based on notes from Sarah Bridle (black), Anthony Challinor (green) and Paul O'Brien (red)

*** STFC Council view: Martin Barstow

Next week, there is a 2 day council strategy meeting: how can we solve the current financial crisis?

Want to stop salami-slicing. 40-60M pound deficit over the coming year, and continuing.

> Speak with one voice and be very clear what you want in terms of future projects.

*** Science Board view: Mike Bode

Was on PPAN over the past years but now on Science Council

> 70% of STFC spend in PPAN areas. Science Board will put together prioritised programme to present to Council based on advice from PPAN, PALS and ASTAB.

*** PPAN view: Bob Warwick

Will start on PPAN next week.

In 2 weeks time I believe: we have a 2 day meeting, with presentations from the 5 advisory panels (NUAP, FUAP,...) and report from GBR. The second day PPAN will have to prioritise projects that don't already have a ranking from the earlier PPAN review - there are 45 such projects (new projects).

It may be that the success rate is not high. If we do have a prioritisation of the 45 projects, how does this fit in with the earlier PPAN prioritisation?

The stronger and the sharper the advice you pass through to PPAN the more likely it is that the prioritisation that PPAN comes up with are consistent with your views.

Mike Merrifield: How does this fit in with the Astronet process. The panels are aware of the Astronet outcomes.

Mike PPAN: I see similarities between what this panel has come out with matches up well with the Astronet roadmap. I made sure this panel had the Astronet info. These panels should be taking it into account.

Trevor Ponman: Is it intended that the advice coming from the panels should focus on science and then PPAN will feed that through into facilities?

Bob Warwick: I think the advisory panels received advice from the office on the sort of questions they should attempt to answer and I believe these are reasonably specific and

says you should prioritise as much as you are able to do. Not easy because this is all in parallel with NUAP, GBR etc. The problem with bringing this together is the timescale involved - PPAN is going to struggle enormously. We have to give statements to council mid-October so there is time to iterate a little bit.

Bob Nichol: We were formed in March and had a longer term attitude. There was a slightly different outlook before the summer and things have changed.

Trevor Ponman: Clearly prioritising the facilities is a tremendous task and clearly the higher it gets up the chain it gets less serious attention.

Dave Carter: I think it has to be science led. The overarching panels have a larger view and are less likely to be led by vested interests.

Trevor Ponman: I was wondering whether if it was left rather vague then each panel will do something different and send something different to PPAN.

Gordon Stewart: how do you see the end-point of this exercise. We all know there are new ideas and opportunities coming along. Over what timescale is there flexibility built into the process.

Martin: We're not at that stage at the moment. Everything is being reviewed - not just astronomy. The big facilities e.g. Diamond will all come under equal scrutiny.

Martin: The aim is that the process should come up with a sustainable affordable program for STFC. It is accepted that somewhere there could be some very large pain for a community. Hopefully this will allow flexibility for those that remain. If you don't have a clear direction coming out of this process then you are very vunerable.

Phil Diamond: Is the 40 to 60M is near cash. Can you estimate what fraction of the near cash budget this is?

Simon Berry: 10%

> Barstow: 20 per cent. Assumes paying back 20M loan.
>
> Multiple responses that this sort of funding needs to be in place along with technology support, protection of the grant line and fellowships. FUAP has ranked such things high.

Bob Nichol: For FUAP, we have taken that on as something to look at. We are aware of the issues of data analysis, data storage etc. It wasn't given as part of our remit but we have taken this on.

Jonathan Tedds: Is this true for NUAP?

Mike: I think the panels should be aware of this.

Angela Taylor: How about technology for new projects fit in?

Bob: It depends what the source of the funding is. If it is a rolling grant then the size of the grants line will come from council, as advised by science board.

Martin: Council defended the grants line very firmly last round.

Angela Taylor: How does that tie in with the science from these panels>

Bob Nichol: We certainly in FUAP have interpreted "facilities" quite broadly and have decided we are interested in anything that affects the health of our science output, whether students

*** Giles Hammond from PAAP

Mix of theory and experiment on the panel. Jim Hinton is in the audience today.

What is particle astrophysics: projects which measure and characterise the Universe utilising particles and radiation (including "new windows").

* ASPERA review: European strategy for particle physics

ASPERA is a network of national government agencies coordinating particle astrophysics across Europe.

Came up with the ASPERA magnificent seven (Sep 2008): list of 7 key experiments.

- A ton scale detectors for dark matter search

- ...nature and mass of neutrinos

- ...proton decay, neutrino

- Cherenkov Telescopes

- neutrino telescope

- cosmic rays

* Questions in Particle Astrophysics

list of about 15 questions in 3 categories:

- Cosmology and the early universe
What is the nature of dark energy and how has it affected the expansion history of the universe.
What is the origin and what are the properties of primordial
fluctuations in the early univeres? What is the imprint of these
fluctuations on staochastic backrounds (e.g. the CMB...)
...

- Fundamental particle physics
...

- High energy universe
...

* PAAP community questionnaire

Questionnaire went public on June 9th, with 6 parts.

Chris Haniff: You had a tableau about risks, opportunities etc - how did you go about translating that into the final slide?

Gordon: You got about 150 individuals for a budget of about of a billion. Does this mean the community size will increase?

Giles H: I think there will be a bigger community. e.g. gravitational wave detection will lead to an increase in the field size.

Angela Taylor: People in my field (CMB) wouldn't have known about this questionnaire.

Bob Nichol: We have in the last couple of months done a much better job of coordinating things. e.g. Giles is here today.

> Bob Nichol: summarised the draft FUAP report submitted to PPAN. Science questions considered first and then facilities required to deliver that science. Also summarised some comments to the advisory panels from a meeting with Richard Wade and John Wormsley. They noted the PPAN area is a large fraction (perhaps too large) of the total spend, particularly when subscriptions are included.

Giles: There is room for improvement to make these consultation exercises more all-encompasing. The survey was mailed out to the particle astrophysics community via the hi-phi network. There is room for improvement.

*** Bob Nichol: FUAP

Bob N: My understanding at that meeting was that we cannot touch the subscriptions.

Mike: These are determined by international treaties. STFC is making ht position clear to our partners to look for opportunities to reduce what we contribute.

Mike Merrifield: A general point: it seems like you are in danger of being taken seriously. So you have to be more pragmatic, so there is not point in asking for something that isn't going to happen, and then we end up getting nothing out of the process.

> Mike Merrifield: pointed out that rankings will get taken seriously so we must be realistic. Need to consider only the highest priorities and what happens if we don't get them.

Bob N: When we started we were science driven, and we will remain science driven.

> Nichol: Don't have all information available to us (costs etc.) to do much more than prioritise on science.

Mike M: I worry we will stitch ourselves up.

Trevor Ponman: The thing that bothers me about the prioritisation is that there is a disconnect between what you've done and what PPAN wants. I think you should list facilities for each of the science questions.

> Trevor Ponman: perhaps FUAP and NUAP should coordinate prioritisation process and rank facilities. Several similar comments.

Bob: Within those lists of facilities we took into account the science questions and their rankings. Some things are not in the box because of the ranking of the science questions.

Trevor: If you don't rank things in the boxes then people who know less will do it for us.

Bob: We did discuss today having a second band of prioritization within those boxes. The question is what we can get done in time.

Gordon Stewart: For example in galaxies you have a question "how do galaxies form and evolve". My understanding is that feedback is important. But I see that feedback is priority B. When I look at the list of facilities there is limited facilities on the feedback question.

Bob N: Please fill this on the questionnaire.

Martin Hendry: I was pleased to see theory and people are highly ranked. How did you come up with this ranking.

Bob: When we made the list of facilities then theory was in every box and there was a lot of feedback about it. ...

Martin: Giles identified the cost as an important, and theory and people are relatively cheap.

Sakrapash (Cardiff): Thank you for doing this job. It is extremely hard. I think the questions you have finally outlined are excellent. For
facilities I get the sense that you have focussed more on the A grade questions. I think it is important to include other things as well. For example LISA was recommended e.g. by BEPAC report in the US. To leave something like LISA out completely will mean that other people .

Bob: Should we attempt to rank the facilities in the table.
yes 5
no 20

> Result: Majority say do not rank.

Trevor: I wasn't suggesting ranking them but map to questions.

Overwhelming vote to place the facilities against the ranked questions.

Bob: I believe NUAP did this...

Tom H: We are going to identify some of our questions as highest priority. We are going to include some information on community feedback on facilities.

> Tom Hardquist: NUAP are *not* ranking facilities but do identify mapping of facilities to questions.

Paul Alexander: There are a lot of facilities that you haven't listed. Are you intending to have a commentary on why you haven't listed them. e.g. e-MERLIN.

Bob: We were planning on having a commentary on why things are in the table.

Paul O'B: We could have a second tier.

Paul A: I think if you don't do anything then where does that leave people's view of where these things lie - people who are higher up the food chain.

Bob: A good reason for having a second tier is that they may be able to fit some of these things

Who thinks we should do a second division?
~10 yes
~10 no

Gerry Gilmore: You said you don't have the info to do that.

Bob: Yes we don't have the info on cost, timeline etc. We could try to make a second division based on science.

Mike M: The danger is that you put everything into the second division and it makes us look weaker.

Andrew King: Why don't you also list the things you do not want?

Nichol: We are Trying to be positive.

Richard McMahon: The GBFR are dividing things up according to cost: high, medium, low. And we're ranking things within that. We were supposed to be looking at the period after 2012 - that was our brief and we are doing that. Someone will have to join this up. We have asked people tlot rank facilities according to what they use, and what they think about other facilities. We meet next week. Our document will be made public.

Bob: As you know, we've had a sneak preview, and that was very helpful. We've tried to factor that in and come up with something independent yet not totally different.

Giles Hammond: To make one thing clear in the presentation from the PAAP. There was a table looking at impact and cost. In the list that was presented we were not prioritising in terms of cost, but the level of funding.

Simon Garrington: Your document mentions the requirement for radio observations in several places, but the only radio telescope in the next 5 years is LOFAR. Is the panel confident that all those questions can be addressed by LOFAR at such low frequencies?

Paul Alexander: Did you make any assumptions about continued access to non-UK facilities - that we don't pay for. Are there assumptions that we will have access to other things?

Bob: There are things that I personally have assumed we would have access to e.g. SDSS. But this hasn't been used as a negative e.g. we still say we should do a galaxy redshift survey.

Paul: It is extremely positive - we have got a lot out of other facilities.

Jim Hough: I'm very pleased to see studentships down. I wonder if you could be persuaded to add advanced fellowships. The AFs are under threat. This would be very valuable.

Bob: We had PDRAs there. In my mind this includes fellowships. We will make that explicit.

Gerry Gilmore: On your list of critical priorities I think that the grants line and studentships is all very positive and I think everyone would agree. Your point 3 is the only negative thing in the whole document. Was this a typo?

> Gerry Gilmore: "Don't spend money duplicating what you can do with exisiting subscriptions" -- is negative sounding and is a cost-implementation issue in contrast to other statements.

Bob: Our thought process here is that we are spending half the budget on these big subscriptions. We wanted to make a positive statement here and we want to make the most use of these facilities. Lets get STFC to help this happen e.g. we should be more involved in TACs etc. We were attempting here also to help make some prioritisation.

Gerry: This isn't code for saying don't invest in the AURORA programme?

Bob: No.

Gerry: That would have been good!

Chris H: You mentioned in the feedback to leave space for unknown science. Is this in the spreadsheet of facilities?

Bob: No. We have a paragraph about this in the science part of the document. It is difficult to turn this into specific facility. If you have ideas please tell us.

Martin Hendry: If as we commented a moment ago, we are to talk up the fellowship programme, this is a way to help with the unexpected.