Science Strategy Document for the Far Universe Advisory Panel (FUAP)

Introduction

We present the initial Science Strategy document for the Far Universe Advisory Panel (FUAP) to the Particle Physics, Astronomy and Nuclear (PPAN) Physics Science Committee of STFC. 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 extra-galactic community, which we will update over the coming years with community input, which will inform PPAN and STFC with far universe science priorities for the coming decades.

- **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 programmes concerned with the global properties of our galaxy, with objects beyond our galaxy, and with cosmology*." We plan for close coordination between this panel and other STFC advisory panels and reviews. In particular we will work closely with NUAP[2] and PAAP[3] regarding any overlapping science areas. We will also coordinate with the Ground-Based Facilities Review[4] and a preliminary version of our science strategy below was included in their consultation document.

We are acutely aware that the STFC community is often asked to participate in these consultation exercises, and we appreciate this concern when we are asking for community input. We stress that FUAP is taking a long-term approach, and our philosophy is akin to that in the previous Astronomy Advisory Panel (AAP)[5], which was part of the old PPARC advisory structure. Your input will be vital, and we ask for your patience as we set-up these panels/reviews and work together to achieve a long term plan for UK astronomy.

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

Public Consultation

Within the first stage of public consultation by FUAP, we are asking the community for feedback on our initial science strategy presented below. To streamline this consultation, we ask interested parties to complete our (short) questionnaire by **July 10th 2009**. The questionnaire can be found at

http://research.icg.port.ac.uk/fuap-questionnaire

or is linked from the main FUAP webpage, which can be found at

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

The questionnaire has only two main questions, and its purpose is to ensure that our science strategy properly reflects the vision of the UK community.

Once we have obtained community feedback on the FUAP science strategy, we will start to map facilities (telescopes, satellites, instruments, theory/analysis, etc.) onto this science strategy in preparation for the next stage of the public consultation. This will probably involve a town meeting and/or departmental visits. The details of this next stage of consultation will be announced on the FUAP website (see above), and via the usual STFC email lists. Our goal is to provide PPAN and STFC with our first advice by the end of September 2009, with continued input from there on.

FUAP Science Strategy

Below we provide the initial FUAP vision of the extra-galactic science priorities for the coming two decades. In drafting these initial themes, questions, and text we have tried to be 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 be strong UK leadership). This list is not meant to be an exhaustive description of all the extra-galactic science UK scientists are engaged in.

We have divided our strategy into four main themes, each with four key questions. The questions are written to be understandable to a majority of the public, while the associated text within each theme is designed to be more detailed and at a level understandable by professional astronomers.

1. COSMOLOGY

- What are the physical laws that govern the beginning of the Universe?
- What is the origin of large-scale structures in the Universe?
- What is the nature of the dark matter and dark energy?
- Is our present model of cosmology based on the correct laws of physics and assumptions?

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, and isocurvature modes. 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.

Cosmologists also need to tackle the conundrum of the "dark universe", which now includes two mysterious ingredients: dark matter and dark energy. The basic properties of the dark matter can be probed by cosmological observations, including its temperature and cross-section, and the neutrino mass. 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.

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 and should continue to play a leading role in forthcoming international CMB, radio, optical and infra-red imaging and spectroscopic surveys.

2. FIRST LIGHT

- How and when did the first stars and black holes in the Universe form?
- What are the best ways to find these first objects in the Universe?
- How and when did the Universe become re-ionized?
- How and when did the Universe become enriched with all the complex elements we see today?

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 to then form into newer stars. Observationally, this must have happened by z~7 as we can observe massive galaxies at this redshift with stellar masses a billion times the mass of our Sun.

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.

Beyond the study of the first objects, we know that at z>5 the neutral hydrogen made at recombination (z~1100) was ionized again. This must have occurred as a result of the formation of the first 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.

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).

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, reionization.

3. GALAXIES

- How do galaxies form and evolve?
- What is the role of environment and interactions in galaxy evolution?
- What are the contents of galaxies and the details of their internal structures and mechanisms?
- What lies between the galaxies?

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, feedback from supernovae and active galactic nuclei).

In the next two decades, new radio, optical, X-ray and gamma-ray facilities will be used to study galaxy formation, by probing the Universe to unprecedented depth in time and mass using many complementary techniques. New insights will also be gained into how stars, dark matter, central massive black holes and increasingly, the neutral and cold gas are assembled in galaxies as a function of time. Astronomers will probe the internal kinematics of stars and gas in galaxies to high redshift using the next generation of radio telescopes, extremely large optical telescopes and integral-field spectrographs. Nearer home, our own Galaxy will also be studied in unprecedented detail with both ground-based facilities and space satellites.

In parallel, wide-field surveys of the Universe will 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 global properties of galaxies. Such research will be performed in tandem with improved numerical simulations (with greater spatial and mass resolution), incorporating more realistic astrophysics of star formation, magnetic fields and accretion.

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 facilities.

4. EXTREME ASTROPHYSICS

- Do our laws of physics on Earth apply under extreme conditions in the Universe?
- What is the astrophysics behind accretion of matter and energetic feedback around compact objects?
- What are the sources of gravitational waves and neutrinos?
- How and where does relativistic particle acceleration occur?

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.

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 dragging” 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, while large amounts of energy are deposited into the host galaxy and beyond helping to drive star formation, regulate galaxy evolution and heat the ambient medium. Observations of gravitational waves and neutrinos provides 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.

The UK has an excellent track record in this area, leading both the construction and exploitation of facilities that make use of naturally occurring cosmic environments to test the laws of physics. To ensure continued UK leadership in this research area, astronomers need a multi-wavelength view of the Universe, with high-resolution observations in time, frequency and space.