Towards the Establishment of the Philosophy of Cosmology at Oxford

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'All science is cosmology' (Popper).

Oxford University is home to the largest concentration of philosophers working on the foundational theories of physics world-wide. These theories – thermodynamics, Einstein's theory of general relativity, and quantum theory – are the core disciplines of modern cosmology, a field in the midst of a golden age of discovery. Hitherto they have been studied in isolation by philosophers: the time is ripe to launch a new initiative in which they are studied as a unity in cosmology.

We see need and opportunity. Now is a time of astonishing observational discoveries in cosmology, and of theorizing awash in speculation on questions which from a physical point of view are unfamiliar. The universe is a unique physical system which can only be studied 'from the inside', and which appears of necessity to be causally closed. Does it admit of an 'external perspective' at all? Other questions apparently fundamental to the nature of the universe can turn out to bear equally on our own particular location and perspective within it. However, there is little consensus on how far this kind of reasoning can go, or which of these questions can thus be solved. Philosophy of cosmology as a new interdisciplinary approach to cosmology will yield new ways of identifying and articulating foundational problems in the field. Several of them are philosophically familiar – old and hoary problems, even, that have been debated for centuries – but their connection with observation is new; whilst others again are utterly new. In short, cosmology at the dawn of the 21st century presents us with conceptual challenges largely new to physical science and the potential to address them in a new interdisciplinary array.

We propose to develop the philosophy of cosmology as a new branch of philosophy of physics through several interconnected means: by producing high quality publications and hosting workshops and conferences on cosmology, but also by boosting the number of new researchers entering philosophy of physics. To this end, we will create a new one-year masters-level degree course at Oxford, to be called the MSt in Philosophy of Physics, intended as a route into the DPhil in Philosophy for graduates interested in foundations with outstanding physics degrees, but with no formal training in philosophy. We aim to provide bursaries for international students, so as to be able to complete with well endowed but conventional programmes in the U.S. and elsewhere in Philosophy or in Physics.

Because these are challenges for tomorrow's generation of physicists and philosophers, and in order to publicize these opportunities for the young, we propose to establish a schools outreach programme, in collaboration with partners, to boost awareness of cosmology as a discipline, and of the fundamental questions it is struggling to answer. It would explain the various ways to

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eventually do research in the field, starting with the most relevant undergraduate degrees. This we hope will boost applications from high-fliers in physics and mathematics to the Oxford Physics and Philosophy undergraduate degree, one of the pre-eminent courses of its kind and the only one in the English-speaking world to offer dedicated philosophy of physics courses in each of the four years of the degree.

In this way we aim to nurture the field of philosophy of cosmology at each stage of operation of the University, from undergraduate recruitment, production of teaching materials, and public outreach, to teaching undergraduate courses in physics and philosophy, establishing new graduate teaching structures, hosting research conferences, inviting visitors, and research and publications.

1. What is philosophy of cosmology?

A physical theory does not wear its philosophical commitments on its face, except for a thin veil of operationalism – a commitment that deflects, rather than sharpens, philosophical debate. Yet every physical theory that has achieved the status of genuinely universal application – Newtonian mechanics, thermodynamics, relativity, and quantum mechanics—has been the subject of intense philosophical controversy. These theories have all, in their various ways, transformed the philosophical landscape, and influenced cultural and intellectual life in the widest possible sense. This was manifestly true of the Copernican revolution. The debate over absolute and relational motion was quintessentially a debate over questions in cosmology, of how the universe as a whole should – or could – be conceived. But philosophical arguments mounted at a very high level of generality have rarely affected physics in return.

Cosmology, however, may well be a special case, for reasons already alluded to. The present situation in cosmology presents special challenges to philosophy, as well as special opportunities. Cosmology is, by definition, a science of universal application, grounded only on universal principles. It is also, by definition, more complex than any of its constituent disciplines, which includes all the fundamental theories of physics. No wonder it is intellectually challenging: it engages directly with a class of problems that have always been a source of fascination to philosophers – of ultimate causation, limits to explanation, the reason there is something rather than nothing—whilst using the full array of mathematical, conceptual and experimental resources of physics.

But that is not to say philosophers of physics do not bring skills of their own to the field. Of course they do: most notably, expertise in dealing with two abiding sources of mystery for most working physicists: the measurement paradox of quantum mechanics, and the meaning of single case probability. These are mysteries of very different orders of difficulty, philosophically speaking, and with very different kinds of solution, but they both impact in central ways on cosmology; without clarity on these scores there is very little hope of real progress in solving its foundational problems. The measurement paradox is a core problem in philosophy of physics; philosophers of physics are well versed in the foundations of probability theory, Bayesian epistemology, confirmation theory, and problems of inductive methods and probability theory more generally throughout the sciences. These are bread and butter issues in philosophy of science.

The difficulty with single-case probability is often thought to arise in cosmology because the universe is singular. What if it is a plurality, a ‘multiverse’, as arguments from several theories have indicated? But now the multiverse is given only once, and the same questions appear. As Ellis, Kirchner and Stoeger put it:

> Why this multiverse with these properties rather than others? What endows these with existence and with this particular type of overall order? What are the ultimate boundaries of possibility – what makes something possible, even though it may never be realised? In our view these questions ... cannot be answered scientifically because of the lack of any possibility of verification of any proposed underlying theory. They will of necessity have to be argued in philosophical terms. (Ellis et al, 2006, p.30).

Thus cosmology presents special opportunities to philosophy.

The philosophy of physics, if definition is needed, is physically-informed philosophy, and philosophically informed physics. As such it takes in all-comers – physicists, philosophers, and mathematicians. *Philosophers of physics* make up a narrower constituency. As a distinctive branch of philosophy, their ranks are more recently formed. Their focus is on entrenched, well-confirmed physical theories, and indeed historical theories such as Newtons's theory of gravity, rather than contemporary physics per se.. They have, moreover, tended to focus on a small number of well-defined and fundamental problems – above all on the 'measurement paradox' of quantum mechanics. They have also focused on a debate of even longer pedigree, of absolute vs relative motion in Newtonian and Einsteinian theory, and attendant debates about symmetries.

This methodology has served them well: philosophers of physics have made a significant contribution to the search for solutions to the measurement paradox, and on various questions in the foundations of the classical theories of gravity. Their strengths lie in conceptual analysis, scholarship, and breadth of knowledge, rather than technical depth. Philosophers of physics are unlikely to come up with fundamental new physical principles; they may, however, show more clearly what is flawed in familiar ones, or how broader philosophical resources may be used to solve difficulties already widely recognized. The recent theoretical literature in cosmology shows a very rapid proliferation in speculation, combined with an often uncritical use of statistical methods of inference, and appeal to speculative and poorly understood philosophical arguments and positions (the strong anthropic principle is a case in point). It also engages, usually in a piece-meal way, with foundational problems in its constituent disciplines, particularly quantum mechanics. But their knowledge of quantum foundations – a field of physics in its own right – is usually quite limited.

We conceive the philosophy of cosmology as a field that should be built around a small but fundamental cluster of problems that arise in cosmology and astrophysics, to be studied, where possible, in the light of specific solutions to the measurement paradox of quantum mechanics. In a first approximation, the problems are these: the problem of time in classical and quantum general relativity, the fine-tuning problem, the horizon and flatness problems, the cosmological constant problem, and the problem of the arrow (or arrows) of time. The solutions to the measurement paradox that we are interested in are realist ones: the Everett interpretation of quantum mechanics, pilot-wave theory, and dynamical collapse theories, such as the GRW theory.

I take it these problems in cosmology are familiar. Here I shall not comment on them further but sketch an appropriate pedagogical setting in which they can be systematically studied – a cosmic pedagogy. We are interested in particular in establishing graduate teaching structures in philosophy of cosmology, presuming expertise in philosophy of physics in general (and hence broad familiarity with quantum mechanics, quantum field theory, the foundations of statistical mechanics, and relativity theory).

2. Cosmic pedagogy

There follows a sketch of the subjects or areas and sub-areas that would be taught in graduate classes in philosophy of cosmology.

2.1. The 'God's Eye' view

What is an absolute conception of the world? What is thought of objects as they are in themselves? These questions were central to early Modern Philosophy, from Descartes, Newton, Leibniz, and Kant. They did not disappear with the advent of relativity and quantum theory in the 20th century:

(i) How is the universe to be represented in our physical theories?
- realism and anti-realism in physics and generally.
- mathematical representation of the world, its uses and abuses.
- symmetry as a guiding principle
- emergent classical space-time vs. fundamental ontology

2.2. The past hypothesis and the arrow of time

From a philosophical point of view, one of the surest grounds of reasoning concerns the second law of thermodynamics, and the apparent need for an enormously special (low-entropy) initial condition of the universe. But does it really follow that to explain the success of thermodynamics in everyday applications in our local vicinity *the universe had to have a special beginning in time*?

This reasoning, if valid, is remarkable. Already it poses unresolved questions at the level of the definition of entropy – presumably total energy – of gravitating systems, a subject which is contentious even in classical GTR. It warrants critical examination of the usual premises of this deduction as well as its validity. Equally obviously, the same question can be restated (and with greater right) in the context of quantum theory. After all, we know that classical radiation theory was inconsistent with thermodynamics (this the 'ultraviolet catastrophe'): why think classical statistical mechanics (in which these debates are usually couched) any different when it comes to the thermodynamic arrow of time? It may be their domain of validity is restricted to the steady state.

There is, however, a deeper question that came into steady focus in physics only in the last quarter century, namely: what is time? This might seem the right one to begin with. That it is linked with Mach's principle is the extraordinary result of Julian Barbour's pioneering work on Mach's principle in this period.

(ii) What is time?
- 4-dimensionalism; philosophy of time more generally
- Mach's principle; Machian vs 'metric-realist' concept ions of time.
- the problem of time in the constrained Hamiltonian formalism
- closed time-like curves; time machines.

(iii) Entropy and irreversibility: Must the universe have had a beginning, and if so what was its nature?

- The 2nd law, low-entropy initial conditions and arrow of time
- Temporal bias: distinguishing between past and future correlations
- Anomalies of gravitational statistical mechanics

2.3. *Issues in classical 'cosmology' and the underlying physics of the universe:*

A spatially infinite matter distribution poses problems for Mach's principle in Barbour 's sense, however; it also poses a special problem to Newton's theory of gravity. The infinity of space is built into Newtonian and non-relativistic cosmology more generally:

(iv) Newtonian and non-relativistic cosmologies

- Island universe
- What is the spacetime of Newton's theory of gravity?
- Mach's principle
- Implications of spatially or temporally infinite universes
- reparameterization-invariance and the problem of time in the constrained Hamiltonian formalism

The full implications of an infinite universe have been well-explored by Tegmark (his 'level 1 many worlds'); they are astounding all the same.They impact directly on the use of probability theory in evaluating cosmological data, and above all on the anthropic principle. General considerations are as follows:

(v) What is probability from a classical cosmological viewpoint?

- The cosmological principle and the anthopic principle
- Observer selection effects and 'a priori' probability distributions.
- probability and initial conditions; 'typicality'.

All of this is background to the main agenda, the pursuit of cosmology as a contemporary empirical discipline, as well as a theoretical and philosophical one.

2.4. Issues within present-day cosmology as an observational discipline.

(vi) The observed universe

- Probability in the analysis of CMB
- Dark energy and the cosmological constant
- Dark matter: reality or illusion
- experimental probes for infinity

(vii) The cosmological problems or pseudo-problems

- the flatness problem
- the horizon problem
- dark energy –why now? Why so small?
- how special was the early universe?

2.5. Quantum Cosmology and quantum gravity

Quantum cosmology is inherently problematic - there is no established theory of quantum gravity. There are, however, ‘toy’ theories (e.g. non-relativistic quantum gravity) that are physically deficient but that are at least mathematically well-defined. These we may hope to understand. The difficulty, as in any quantum theory but especially in applications to the universe as a whole, lies *the problem of measurement*. The best-known realist solutions include hidden-variables (e.g. pilot-wave theory), dynamical state reduction (e.g. GRWP theory), and Everettian quantum mechanics (the decoherence-based ‘many-worlds’ interpretation). Only the latter applies to the standard model of particle physics (the modifications to quantum mechanics required of the others only seem to make sense in the non-relativistic theory).

(viii) Quantum theory as a universal physical theory

- the measurement paradox
- solutions to the measurement paradox in a relativistic and cosmological setting
- probability and emergence in the Everett interpretation
- zero-point energy in quantum field theory

Ideally, of course, one would like to have a fully-worked out relativistic quantum cosmology. But that requires a theory of quantum gravity. Even disregarding the problem of measurement, no such satisfactory theory exists. But there has been some progress in the most conservative theory of this kind (based on canonical quantization methods and the Hamiltonian formalism), namely loop quantum gravity. However the great bulk of work being done today on this topic is in superstring theory. Some understanding of these two approaches is essential to the philosophy of cosmology. Prior to that, it is as well to be clear on the foundational questions that arise in quantum cosmology in the absence of gravity, i.e. in the standard model:

(ix) Fine tuning in the Standard Model

- the anthropic principle
- multiverse-based explanations
- cosmological natural selection
- design: is an explanation needed?

Any approach to quantum gravity in the spirit of the general theory of relativity must confront the fundamental symmetry of that theory: general covariance. Remarkably, it remains controversial as to how that symmetry is to be characterized.

(x) Quantum gravity: general covariance and the problem of time

- what is general covariance?
- the problem of time in classical general relativity
- Newton-Cartan and Machian approaches to quantum gravity
- toy models (e.g. superspace-based and 2D quantum gravity)

Not all the main programmes in quantum gravity respect this symmetry, however.

(xi) Quantum gravity: the main programmes

- quantum gravity as quantum field theory
- String theory: the string landscape, duality, M-theory
- Canonical quantum gravity; loop quantum gravity
- continuity vs granularity of space-time

2.6. Full circle: where did we come from

Most of the classical questions of (i)-(v) recur in one form or another in (vi)-(viii), but some can be more profitably addressed directly in the context of the standard model (ix), and even in relativistic quantum gravity (x), (xi). We should state them again:

(xii) Are time and space-time emergent?

- What can be timelessly real? From what can time emerge?
- Is the metric tensor of general relativity emergent? Are Einstein's field equations emergent?

(xiii) Are there limits to explaining the origins of the universe?

- The status of initial conditions: laws or brute facts?
- Towards the ultimate theory of structure formation
- 'Top-down' vs 'bottom-up' cosmology
- Can we ask what happened "before the big bang"?

(xiv) What else needs explanation?

- Can the laws of physics themselves be explained? Do they evolve?
- Is mathematics unreasonably effective in physical science? Are physical fundamentals (simples) mathematically fundamental (simple)?
- Why is there something rather than nothing?

3. Why Oxford?

The philosophy of physics group at Oxford is the largest of its kind in the world. It has expertise in all the foundational theories of physics of relevance to cosmology: classical mechanics, thermodynamics, classical and quantum statistical mechanics, quantum mechanics, quantum field theory, special relativity, and general relativity. The philosophy department is also a global leader: it has unmatched strength and depth in several branches in philosophy.

Oxford also has the largest and most diverse physics department in the U.K, with particular strengths in particle physics and astrophysics. The Collegiate University has a long history of multi-disciplinary cooperation in teaching, especially in the interface of physics and philosophy and pure mathematics.

The Physics and Philosophy 4-year undergraduate degree at Oxford is unique in the English-speaking world. It is the only degree course of its kind which integrates the two core disciplines in a mandatory framework built around dedicated philosophy of physics courses in each year of the programme. It is designed so that graduates of the degree are qualified to compete at the highest level for places in graduate programmes in either Physics or Philosophy.

4. Why now?

We live in a golden age in theoretical and observational cosmology. The situation is likely to be further transformed, with potentially large impact on the Standard Model, as LHC comes on line. It is a transformative time, at which the greatest enigmas that have ever confronted the human mind are coming within theoretical and empirical grasp. They are questions that have always lain at the core of the philosophical imagination, in recent centuries and over the millennia. It is a time in which philosophical skills and knowledge of philosophy and allied fields may be able to make a fundamental contribution to what is surely the greatest intellectual enterprise to which we can ever aspire.

5. Funding proposals

5.1. To establish philosophy of cosmology in terms of degree programmes and research

We propose to establish philosophy of cosmology at Oxford in graduate teaching structures, both within a new taught 1-year philosophy of physics masters degree (an MSt in Philosophy of Physics), and at the level of the DPhil research degree in Philosophy. The MSt is to supplement the small trickle of graduate students already trained in both disciplines who typically progress to the DPhil through the extant 2-year BPhil programme in Philosophy.

The new MSt, in contrast, is intended for high-fliers in physics with little or no formal training in philosophy but who wish to do research in philosophy of physics. The backbone of the degree will be a graduate class in research topics in philosophy of physics spread over two terms and taught by members of the philosophy of physics group at Oxford. This class, too, will be an option for those taking the BPhil in philosophy. We expect to develop over a 5-year period teaching competence in research areas in philosophy of cosmology and to run a series of graduate seminars in the field. Appendix B lists the topics the philosophy of cosmology would be expected to cover. We also intend to enhance interest in cosmology among undergraduates taking the Physics and Philosophy degree course at Oxford.

In the process, we will encourage members of the philosophy of physics group to develop new teaching and research interests in philosophy of cosmology - and similarly, members of the astrophysics and theoretical physics to develop interests in conceptual and foundational questions in cosmology. This is, by its nature, an open-ended matter that will depend on individual decisions by members of the various groups concerned, but we propose to put in place three kinds of incentives. The **first** is to have a series of master classes in foundations of cosmology, given by distinguished visitors and by local experts, providing cutting-edge opportunities for learning. The **second** is to increase sharply the demands for graduate teaching and graduate supervision in the field; this is to proceed in tandem with the general goal of producing high-quality research, including doctoral dissertations, by building up a cohort of graduate students working in philosophy of cosmology. The **third** is to establish a research fund to which philosophy of physics faculty (and faculty in allied areas) could bid to develop specific teaching or research projects in cosmology, whether to provide time, teaching or research assistance, or in support of research collaborations.

We intend a ‘big-bang’ approach: quickly to create a cohort of graduate students taking the MSt and BPhil degrees with specific interests in cosmology, with the provision of graduate classes in foundations of cosmology and of partner graduate classes in the Physics Department. To this end we need funding both for graduate bursaries, to be clustered over a relativity short period time – the initial 5 year period – and for 5-year teaching appointments.

We intend to host a series of research workshops on the philosophy of cosmology, including workshops devoted to defining or redefining the field. They will culminate in at least one major international conference, and in the publication of the proceedings (and other solicited papers on the theme) entitled 'the Philosophy of Cosmology'.

Last but not least, we intend to create a purpose-built website devoted to the field, including extensive archiving capabilities, from which audio and video of talks, workshops and conferences can be viewed and downloaded as pod-casts. This will be integrated with the two other Oxford websites I have designed and web-master, 'Everett at 50' http://users.ox.ac.uk/~everett/ and 'Philosophy of Physics' http://users.ox.ac.uk/~ppox/.

5.2. To establish philosophy of cosmology as public and schools outreach programme

We intend to mount a focused schools outreach programme, targeting potential applicants to the Physics and Philosophy undergraduate degree at Oxford. Still in the UK there are hundreds of enormously talented physicists each year who do not even bother to apply to Oxford and Cambridge. Thousands more are unaware of the central philosophical dimensions to many of the most recent discoveries in cosmology, and to physics more generally. A programme of visits to schools – say of the order 3 or 4 per year, to be undertaken by post-docs and graduates from the BPhil and MSt programmes in philosophy of physics – could be organized and carried through at relatively little cost. E.g., a budget of the order of £20K per year would be sufficient for ~200 schools visits per year, or 1000 schools through the duration of the programme.

The Philosophy of Cosmology website will include links to teaching materials and to other sites devoted to public science outreach. It will host videos of public lectures on foundational questions in cosmology, mounted in Oxford and sister institutions interested in promoting the field.

We propose to seek outside partners in the design and preparation of high-quality teaching products. We have one such partner specifically in mind, namely Howard Burton, the founder and executive director of the Perimeter Institute for Theoretical Physics. He proposes the following concrete deliverables:

- an array of educational products will be developed, centred on the wonders and mysteries of cosmology and invoking the expertise of world-leading researchers, at Oxford and elsewhere. These products (utilizing old and new media) would be introduced into schools in the UK and beyond in the manner previously described.

- a separate teacher's manual would be created, in addition to further web-based pedagogical materials for educators.

- regular (i.e. semi-annually) one-day training sessions would occur to introduce junior scientists to the specific nature of the material as well as the particular challenges of communicating to students and teachers

- the University of Oxford would host an annual 3-day teacher workshop to enable a selection of motivated teachers to further develop their skills, offer feedback on our materials and interact with cosmology researchers.

- a prestigious, well-promoted, annual public lecture on cosmology would be given by an internationally renowned scientist during the aforementioned teacher workshop.
- in time, links will be established with other outreach programmes in other countries. The Oxford outreach programme will serve as a test-case and model for how, given the right organizational structures and teaching products, post-docs and graduate students may 'give something back' to their local

6. Aims and objectives

To: –

- identify and explore key philosophical and foundational problems in contemporary cosmology through research publications, conferences and workshops, and new graduate teaching structures.
- establish a new one-year masters 'MSt' degree in the philosophy of physics targeted at physics graduates with little or knowledge of philosophy who wish to work on foundations
- develop classes in philosophy of cosmology suitable for teaching for the new one-year masters programme and existing research degrees at Oxford, in Philosophy and neighbouring disciplines.
- develop undergraduate teaching in philosophical topics important to cosmology (e.g. in foundations of probability, selection effects in epistemology, theory of knowledge de se, scientific rationality, meta-metaphysics, and philosophy of science more generally), and provide for Physics and Philosophy and allied undergraduate degree courses at Oxford.
- create a critical mass of graduate students working in philosophy of cosmology and allied areas in philosophy of physics.
- promote and heighten awareness among the general public and school-leavers, particularly school-leavers in physics and mathematics, of philosophical and foundational questions in cosmology and in physics more generally.
- promote the kind of interdisciplinary trans-national collaboration underpinning the pedagogical enterprise by hosting international workshops, the process to culminate in a major conference on philosophy of cosmology, the proceedings to be published.