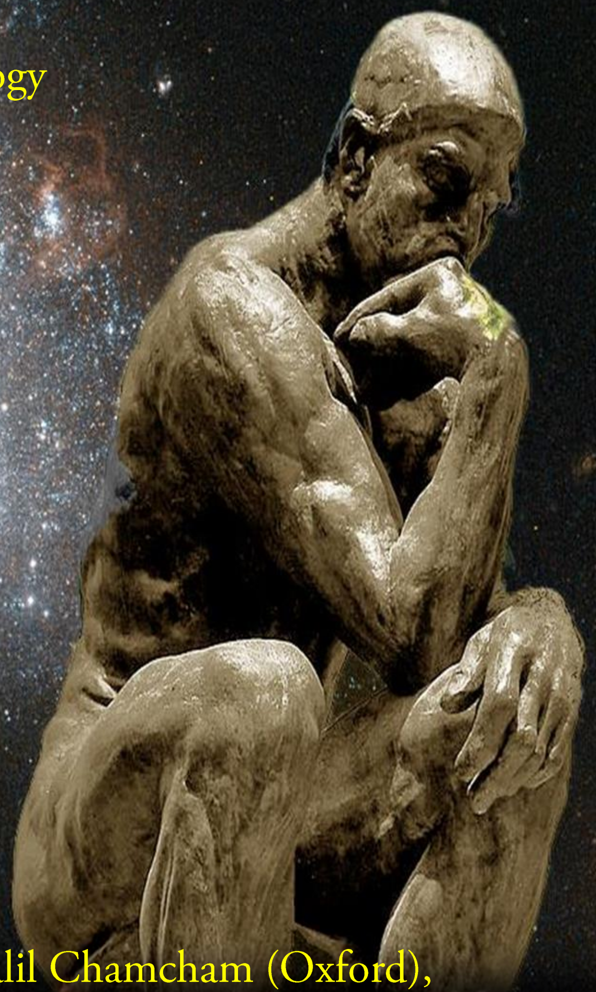
PHILOSOPHY OF COSMOLOGY

UK/US CONFERENCE

12TH - 16TH SEPTEMBER 2014, TENERIFE, SPAIN

TOPICS

What is Philosophy of Cosmology?
Quantum Foundations & Cosmology
String Theory
Inflation
Emergent Spacetime
Gravity
Initial Conditions
Arrow of Time
Laws of Nature
Emergence of Structure
Fine-Tuning
Probabilities



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INTERNATIONAL CONFERENCE

THE PHILOSOPHY OF COSMOLOGY

ABAMA Resort, Tenerife, Spain 12th-16th September 2014

Day 1: Friday 12th September – Arrival: registration **20.00 welcoming drink - 21.00 dinner followed by an introductory talk:** Simon Saunders – Opening Remarks [30 mn]			
Day 2: Saturday 13th			
S1: 9.00-9.05	Joe Silk	Welcome	
9.05-9.50	Rafael Rebolo	The Polarisation of the Cosmic Microwave Background: Perspectives and Challenges	
9.50-10.35	George Ellis	Observability and Testability in ***c***osmology and ***C***osmology: what are the Limits of Science?	
10.35-11.00	Coffee break		
S2: 11.00-11.45	John Barrow	Some Generalities about Generality	
11.45-12.30	Carlo Rovelli	Emergent Time, Space-Time, Gravity	
12.30-14.30, Lunch			
S3: 14.30-15.15	Ofer Lahav	The Enigma of Dark Matter and Dark Energy: Have we been here before?	
15.15-16.00	Joe Silk	Fundamental Issues in Galaxy Formation	
16.00-16.30	Coffee break		
S4: 16.30-17.15	Joel Primack	Cosmological Structure Formation	
17.15-18.00	Jean-Philippe Uzan	Fundamental Structures of Effective Theories	
21.00 onwards, Dinner Talk: Jim Holt – Why is There a World? [30 mn]			
Day 3: Sunday 14th			
S5: 9.00-9.45	Jim Hartle	The Return of the Observer in Quantum Cosmology	
9.45-10.30	Cian Dorr & Frank Arntzenius	Self-locating Beliefs in Infinite Worlds	
10.30-10.55	Coffee break		
S6: 10.55-11.40	Don Page	Observational Probabilities in Quantum Cosmology	
11.40-12.30	Shelly Goldstein, Carlo Rovelli & David Wallace		Round Table
12.30-14.00 Lunch			
14.00 onwards, Excursion to Tenerife Observatory **Dinner at the Teide (Parador restaurant)**			
Day 4: Monday 15th			
S7: 9.00-9.45	Bob Wald	Gravity and Thermodynamics	
9.45-10.30	Tom Banks	Cosmology in Holographic Spacetime	
10.30-10.55	Coffee break		
S8: 10.55-11.40	Brian Pitts	Progress and Gravity	
11.40-12.30	Bill Unruh & Tiziana Vistarini		Round Table

12.30-14.30, Lunch			
S9: 14.30-15.15	Bernard Carr	Black Holes, Cosmology and the Limits of Science	
15.15-16.00	Daniel Sudarsky	Quantum Origin of Cosmological Structure and Dynamical Rduction Theories	
16.00-16.30	Coffee break		
S10: 16.30-17.15	Henrik Zinkernagel	Time, Aesthetics and the Limits of cosmology	
17.15-18.00	Janna Levin, Priya Natarajan, Claus Beisbart & Pedro Ferreira		Round Table
21.00 CONFERENCE DINNER + Concert by Nancy Abrams			
Day 5: Tuesday 16th			
S11: 9.00-9.45	David Albert	Big and Small	
9.45-10.30	David Wallace	The Nature of the Past Hypothesis	
10.30-10.55	Coffee break		
S12: 10.55-11.40	Barry Loewer	Metaphysics of Laws & Time in Cosmology	
11.40-12.30	Dean Zimmerman, Jennan Ismael & Tim Maudlin		Round Table
12.30-14.30 Lunch break			
S13: 14.30-15.15	Chris Smeenk	Testing Inflation	
15.15-16.00	Sean Caroll	Quantum Mechanics in Large Universes	
16.00-16.30	Coffee break		
S14: 16.30-17.15	Luke Barnes	A Beginner's Guide to Cosmological Speculation	
17.15-17.35	Ward Struyve	Bohmian Mechanics and Cosmology	
17.35-17.55	Martin Sahlen	On Probability and Cosmology	
7pm onward: informal meeting to discuss Carroll/Chen model chair: Barry Loewer **Free evening**			
Day 6: Wednesday 17th – Departure			

Session chair:

Chair	**Session**
Pedro Ferreira	S1
David Albert	S2
Priya Natarajan	S3
John Barrow	S4
Sean Carroll	S5
George Ellis	S6
Bill Unruh	S7
David Wallace	S8
Jean-Philippe Uzan	S9
Brian Pitts	S10
Roderich Tumulka	S11
Simon Saunders	S12
Joe Silk	S13
Bernard Carr	S14

Abstracts – Saturday 13th September

The Polarisation of the Cosmic Microwave Background: Perspectives and Challenges

Rafael Rebolo
Instituto de Astrofísica de Canarias

The spectrum and the anisotropy of the Cosmic Microwave Background (CMB) provide exceptional insight on the physics of the Early Universe. CMB data obtained with full sky space missions (COBE, WMAP, Planck) complemented with ground-based and balloon experiments have set stringent constraints on the parameters of the cosmological model and on predictions of inflationary models. The precise measurement of the CMB polarization (E and B modes) will contribute to refine our knowledge of cosmological parameters and may provide evidence for the existence of primordial gravitational waves. I will describe current experimental efforts and recent results on CMB polarisation with special attention to experimental challenges and the limitations imposed by polarised foregrounds. As an example, I will present the new QUIJOTE (Q-U-I JOintTEnerife) Experiment, a Spanish-British collaboration that aims to perform high sensitivity measurements of the polarisation of the CMB and relevant foregrounds in the frequency range 10-40 GHz. The project consists of two telescopes and three instruments exploring a large sky area (5000 sq deg) from Teide Observatory (Tenerife) to obtain Q and U maps of high sensitivity. It will be able to set constraints on the tensor to scalar ratio at a level r~0.05 adequate for independent confirmation of the recent claims by BICEP2 in a very different frequency range.

Observability and Testability in *c*osmology and *C*osmology: what are the Limits of Science?

George Ellis
Cape Town

The nature of a proposed cosmological theory is characterised by a set of features which each raise philosophical issues. The answer may be obvious/taken for granted by the scientist in many cases, and so seem hardly worth mentioning. However cosmology cannot be done without engaging philosophical issues, particularly because it pushes science to the limits. Making them explicit clarifies what is being done and raises issues that need attention. The features to be considered are,

1. **Feature 1: Scope and goals of the theory**
2. **Feature 2: Nature of the theory**
3. **Feature 3: Priors of the theory: the range of alternatives**
4. **Feature 4: Data for the theory**
5. **Feature 5: Outcomes of the theory**
6. **Feature 6: Testing of outcomes**

This talk will consider observability and testability in cosmology in relation to these issues, and how they illuminate and relate to the limits of science.

Some Generalities about Generality

John D Barrow
DAMTP, Cambridge

We show how to determine the specification of the most general cosmological solutions of Einstein's equations. The familiar Friedmann universes and other simple exact solutions are considered in this light. Some examples of the most general known chaotic behaviours will be shown, together with cosmological no hair theorems for inflation, and general solutions near 'sudden' singularities. The full classification of spatially homogeneous cosmologies will be shown together with the surprising effects of compact spatial topologies on their generality. Extensions to higher-order theories of gravity will be mentioned.

Emergent Time, Space-Time, Gravity

Carlo Rovelli
Centre de Physique Theorique de Luminy

I think that in spite of all the wild speculations, too often we forget that the world is quantum mechanical, and this implies that spacetime is only a macroscopic approximation. Before speculating about infinite space, other worlds or extra dimensions, we should learn to do physics with a fundamental framework where time, space and gravity emerge only in the semi classical limit, because this follows directly from what we have already discovered about the world. Doing physics without time and space is possible.

The Enigma of Dark Matter and Dark Energy: have we been here before?

Ofer Lahav
University College London

There is strong observational evidence that our Universe is flat and it consists of three main ingredients: ordinary matter, Dark Matter and Dark Energy.

Dark Energy might be the cause of the observed acceleration of the cosmic expansion.
We comment on cases in the history of Astronomy, which may shed some light on this current established but yet unexplained concordance model of Cosmology. Should the model be understood by adding new entities such as Dark Matter and Dark Energy, or by modifying the underlying theory? For example, the prediction and discovery of planet Neptune can be regarded as analogous to finding a dark component; while explaining the anomalous perihelion precession of Mercury by General Relativity can be taken as analogous to the possibility that modified gravity is an alternative to dark components of the universe.

We also discuss the pros and cons of globalisation and the ‘industrial revolution’ of Cosmology, as well as the ‘cognitive limit' on the size of collaborations.

Fundamental Issues in Galaxy Formation

Joe Silk
IAP, JHU and Oxford

The origin of the galaxies represents an important focus of current cosmological research, both observational and theoretical. Its resolution involves a comprehensive understanding of star formation, galaxy dynamics, supermassive black holes, and the cosmology of the very early universe. It is a field that is largely driven by a phenomenology that depends on our accumulating data taken with the largest available telescopes, both terrestrial and in space, both on the most distant objects in the observable universe and on fossil signatures from the oldest stars in our vicinity. In this talk, I will review our current understanding of some of the most fundamental issues in galaxy formation and describe the challenges that lie ahead.

Cosmological Structure Formation

Joel Primack
UCSC

The now-standard Lambda Cold Dark Matter cosmology is the modern framework within which we try to understand the formation of galaxies, galaxy clusters, and larger scales. This talk will summarize LCDM's remarkable successes in accounting for the large scale structure of the universe and the recent progress in understanding the formation and evolution of galaxies with many important new insights as rapidly improving simulations are compared with rapidly improving observations. The talk will also discuss challenging small scale issues that remain controversial.

Fundamental Structures of Effective Theories

Jean-Philippe Uzan

CNRS/Institut d'Astrophysique de Paris & Institut Henri Poincaré

There is a large freedom in the choices of the structures that enter the mathematical formulations of a physical theory. While the developments of theoretical physics taught us that some of these structures are well suited to describe some classes of phenomena, these choices can only be validated by the mathematical consistency of the theory and the agreement between the consequences of these structures and experiments. In particular, some of these structures may turn not to be fundamental and be replaced by other structures. I will investigate two such cases: the Lorentz signature and the fundamental constants.

Dinner Talk: Why is there a World?

Jim Holt

Why is there a universe rather than nothing at all? Is this question (a) meaningful, and answerable by science (Krauss); (b) meaningful, but unanswerable by science (Weinberg); (c) nonsensical, but harmlessly so (Carroll); (d) nonsensical, and perniciously so (Grünbaum); or (e) meaningful, but the wrong question to ask (Parfit)? I'll help you decide.

Sunday 14th September

The Return of the Observer in Quantum Cosmology

James Hartle
UC Santa Barbara

Observers play a minor role in formulating classical physics. They have a central role in formulating Copenhagen quantum mechanics. In Everett generalizations for cosmology observers are physical systems within the universe that play no preferred role in formulating the theory.

Observers return to importance in the predictions of probabilities for observations of the universe. The most probable universe to be observed is not necessarily the most probable one predicted by its quantum state. Anthropic limits on the results of observations are automatic in quantum cosmology without the invocation of any `anthropic principle'. We won't observe what is where we cannot exist.

Three examples using the no-boundary wave function for the universe's quantum state will be discussed: (1) The prediction of a large number of e-folds of inflation. (2) The prediction of the cosmological constant and the magnitude of the density fluctuations in a landscape where these can vary. (3) The prediction of the CMB in an eternally inflating universe without any `measure' beyond that supplied by the quantum state and a typicality assumption.

Self-Locating Beliefs in Infinite Worlds

Cian Dorr and Frank Arntzenius
Department of Philosophy, NY and University College, Oxford

Recently inflationary cosmology has brought to the fore the problem of self-locating degrees of belief, which previously was largely confined to discussions in the philosophy literature of somewhat esoteric scenarios such as ‘Sleeping Beauty’. We begin by examining, by means of simple examples, possible rules for the formation of self-locating degrees of belief in finite cases, including largely neglected scenarios in which there is no exact duplication of experiences. We pay particular attention to the problem as to what should count as possible locations (e.g., should we have a non-zero prior degree of belief in being a chimpanzee?), and to the way in which objective chances should constrain our prior degrees of belief (via a form of the 'Principal Principle'). We then turn, again by means of simple examples, to infinite cases, paying particular attention to cases in which there are distinct natural ways of taking limits of relative frequencies. We argue in favour of a 'compromising' view, according to which our prior degrees of beliefs should be a weighted sum of such distinct natural ways of taking limits of relative frequencies. Finally we argue that such a 'compromising' view makes most sense of the practice of cosmologists with respect to the 'measure problem' associated with 'Boltzmann Brains' and 'Boltzmann Babies', and that such a compromising view is our best hope for solving this measure problem.

Observational Probabilities in Quantum Cosmology

Don N. Page
Department of Physics, University of Alberta

In quantum cosmology, we need not only the dynamical laws of physics (e.g., the algebra of quantum operators) and the quantum state of the universe (giving expectation values to the operators) but also rules for extracting observational probabilities from the quantum state. I have shown that these probabilities cannot be given by Born's rule interpreted mathematically as the rule that the observational probabilities are given by the expectation values of projection operators [1-4]. However, the next simplest option seems to be that the relative probabilities are given by normalizable expectation values of other positive operators, one for each observation. Finding these operators is one way to state the measure problem of cosmology. Some preliminary ideas for part of the structure of these operators will be discussed, as well as how these ideas fit within a Bayesian analysis for ultimate theories.

References:
1. D. N. Page, "Insufficiency of the Quantum State for Deducing Observational Probabilities," Phys. Lett. B 678, 41 (2009) [arXiv:0808.0722 [hep-th]].
2. D. N. Page, "The Born Rule Fails in Cosmology," JCAP 0907, 008 (2009) [arXiv:0903.4888 [hep-th]].
3. D. N. Page, "Born Again," arXiv:0907.4152 [hep-th].
4. D. N. Page, "Born's Rule Is Insu_cient in a Large Universe," arXiv:1003.2419 [hep-th].

Monday 15th September

Gravity and Thermodynamics

Bob Wald
University of Chicago

Developments during the past 40 years have brought to light a deep connection between gravitation and thermodynamics. The most prominent instance of this connection is the fact that black holes obey the laws of thermodynamics, including the "generalized second law." I will review these results and briefly discuss some recent results that further extend this relationship by showing that the dynamical stability of a black hole is equivalent to its thermodynamic stability. However, I will argue that this does not imply that a black hole is simply a "lump of coal," or even a holographic lump of coal.

Cosmology in Holographic Spacetime

Tom Banks
UCSC

I outline a quantum model of cosmology based on the formalism of Holographic Space-time. That formalism introduces an infinite number of quantum systems, one for each element of a discrete sampling of a congruence of time-like trajectories. Following Jacobson (1995) space-time encodes the hydrodynamics of this collection of quantum systems and is not a fluctuating quantum variable. The structure of the many Hamiltonians, and a specification of overlap consistency conditions for information shared between the different systems encodes both the causal structure and conformal factor of the metric in purely quantum terms - dimensions of preferred tensor factors of Hilbert spaces. Along a particular trajectory, the number of degrees of freedom coupled together grows with time and by abuse of language we call this "growth of the Hilbert space". The variables are sections of the spinor bundle over the holographic screen (maximal area d-2 surface on the boundary) of each causal diamond, with a cutoff on the spectrum of the screen's Dirac operator that encodes its area. Subsystems localized in the bulk of a diamond are described in terms of constraints on these spinor variables. The Hamiltonian is the trace of a polynomial in matrices constructed from bilinears in the spinors.

The model has a completely non-singular beginning, in which the causal diamond along each trajectory is too small to have a hydrodynamic description. The simplest cosmology is one in which the Hamiltonian along each trajectory is a random fast scrambler, converging in the limit of large diamonds to a 1 + 1 dimensional conformal field theory. If we stop the growth of the Hilbert space along each trajectory at some fixed large size the hydrodynamic metric is a flat FRW cosmology with energy density the sum of two components with p = \pm \rho. Only a single horizon volume of the ultimate de Sitter space is physical. This cosmology is homogeneous isotropic and flat for arbitrary initial conditions, even if no de Sitter era occurs. It has no local excitations.

A cosmology more related to our own is constructed by allowing the Hilbert space to grow along each trajectory but constraining the states so that multiple horizon volumes of de Sitter space are encoded as diagonal blocks in a large matrix, with the off diagonal components set equal to zero. This is a low entropy state, which MUST be assumed in order to obtain local excitations in the universe. It produces an approximately homogeneous and isotropy cosmology with fluctuations that can be interpreted as the thermal fluctuations in individual horizon volumes.

If we choose the time dependence of the Hamiltonian appropriately and the number of e-folds is large, the Hamiltonian converges to a generator of the de sitter group and the correlations have approximate SO(1,4) invariance, which fits the data. Primordial tensor fluctuations exist but their size can only be estimated. They have zero tilt. The role of inflation in this model is to produce correlated localized excitations, NOT to explain homogeneity, isotropy and flatness.

The number of e-folds is again fixed by fiat, but more e-folds correspond to a less probable state. If we now continue to expand the Hilbert space after inflation we enter a p = 0 phase in which the erstwhile dS horizon volumes behave like black holes, which decay and produce a Hot Big Bang universe unless

they combine and collapse into larger black holes. The latter behavior occurs if the number of e-folds is not large enough. The most probable universe is thus one in which the number of e-folds is minimal, subject to the constraint of avoiding combination and collapse of the localized excitations.   Crude estimates put this minimal number at 7, while we need from 12-16 e-folds to explain the data.   Black hole decay produces a new source of gravitational waves, directly related to the scalar fluctuations in the black hole density. The long wavelength correlations in this radiation thus share the scalar form but are smaller by the inverse of the number of other effectively massless degrees of freedom.

Progress and Gravity

J. Brian Pitts
University of Cambridge

Reflective equilibrium between physics and philosophy, and between GR and particle physics, is fruitful and rational. I consider the virtues of simplicity, conservatism, and conceptual coherence, along with perturbative expansions.

There are too many theories to consider. Simplicity supplies initial guidance, after which evidence increasingly dominates. One should start with scalar gravity; evidence required spin 2.

Good beliefs are scarce, so don't change without reason. But does conservatism prevent conceptual innovation? No: considering all serious possibilities (Feynman, Weinberg, *etc*.) could lead to Einstein's equations. (The rehabilitation of massive gravity shows that 'progress' is not unidirectional.)

GR is surprisingly intelligible. Energy localization makes sense if one believes Noether mathematics: an infinity of symmetries shouldn't produce just one energy. Hamiltonian change results from Lagrangian-equivalence.

Causality poses conceptual questions. For GR, what are canonical 'equal-time' commutators? For massive spin 2, background causality exists but is violated. Both might be cured by engineering a background null cone respected by a gauge group*oid*.

Perturbative expansions can enlighten. They diagnose Einstein's 1917 'mass'-Lambda analogy. Ogievetsky-Polubarinov (1965) invented an infinity of massive spin 2 gravities---including ghost-free de Rham-Gabadadze-Tolley (2010) theories!---perturbatively, and achieved the impossible (*c.f.* Weyl, Cartan): spinors in coordinates.

Black Holes, Cosmology and the Limits of Science

Bernard J. Carr
Queen Mary, University of London

The boundary between physics and philosophy is inevitably blurred at the frontiers of knowledge. Since the history of physics has involved the extension of knowledge outwards to progressively larger scales and inwards to progressively smaller ones, it is not surprising that the frontiers associated with the smallest and largest scales have always bordered on philosophy. The macro frontier is the domain of cosmology and I use the term 'metacosmology' to describe ideas on this border. Although some of the questions addressed by cosmologists were once regarded as being in the domain of philosophy, cosmology is now firmly established as a branch of physics. Nevertheless, it has often had to struggle to maintain its scientific respectability and more conservative physicists still tend to regard some of its speculations (eg. the anthropic principle and the multiverse) as going beyond the domain of science. The micro frontier is the domain of particle physics and similar issues arise there. Some people argue that we are close to a Theory of Everything, with M-theory and its extra dimensions being the front-runner. However, we are a long way from being able to test this theory, so others regard this as mathematics rather than physics. Since M-theory and the multiverse represent the current macro and micro frontiers of physics, it is no surprise that they both border on philosophy. However, an important lesson of history is that these borders have always evolved, so that today's metacosmology becomes tomorrow's cosmology. In this talk I will discuss three topics, involving black holes and cosmology, which might be regarded as being on this border. The first involves the connection between black holes and the uncertainty principle, which I term the Black Hole Uncertainty Principle Correspondence. The second involves the question of whether black holes can persist through or be generated by a cosmological bounce in cyclic models. The third involves a proposal linking the flow of time and brane cosmology, where one models the universe by a 5-dimensional Schwarschild de Sitter solution. All three problems border on philosophy in the sense that they are very speculative and cannot currently be tackled very rigorously. Nevertheless, they are interesting and could eventually be amenable to a proper calculation.

Quantum Origin of Cosmological Structure and Dynamical Reduction Theories

Daniel Sudarsky
Universidad Nacional Autonoma de Mexico

Inflationary cosmology contemplates a quantum origin of the seeds of cosmic structure. The starting point is a homogeneous state of a quantum field. However, it is clear that structure is intimately associated with inhomogeneities. In attempting to reconcile the symmetry of the former, with the lack of symmetry of the later, one comes face to face with conceptual/ interpretational issues in quantum theory. We propose that these can be addressed by modified quantum theories involving ``the spontaneous collapse of the wave function". Interestingly, the introduction of such modifications seems to be generically associated with (in principle) empirically accessible signatures in the CMB which moreover depend on the details of such modified theories.

Time, Aesthetics and the Limits of Cosmology

Henrik Zinkernagel
Department of Philosophy, University of Granada

In the fourth century BC, Plato suggested that the notion of time in cosmology is closely related to ordered motion. This relation also lies at the core of relativistic cosmology, and it leads to limitations as to how far back in time one can extrapolate cosmological models. In particular, such extrapolations become problematic if an early quantum phase of the universe is contemplated, e.g. at the onset of inflation or in a quantum gravity 'epoch'. I indicate how this also limits the prospects for a meaningful notion of time in multiverse scenarios. In the second part of the talk, I discuss the close historical link between cosmology and aesthetics. Plato associated cosmological beauty with the uncovering of order and symmetry in the mathematical description of the universe. As evidenced in history, however, aesthetic appreciation of the cosmos also includes the category of the sublime, which relates e.g. to the infinite and that which may be beyond rational understanding. In this broader aesthetic context, the limits of cosmology should not be seen as embarrassments to be overcome, but rather as pointers to the inherent attractiveness of cosmological questions.

Tuesday 16th September

Big and Small

David Z. Albert
Columbia

I will discuss several perennial objections to the neo-Boltzmannian idea that all of the time-asymmetries of our everyday macroscopic experience of the world can ultimately be traced back to the initial macro-condition of the universe. The focus will be on a particular sort of puzzlement - which has been expressed by a number of different investigators in a number of different contexts - about how it could possibly be the case that (for example) my local and visceral and immediate awareness of whether a certain baseball happens to be heading towards me or away from me is somehow anchored in the lowness of the entropy of the world 15 billion years ago.

The Nature of the Past Hypothesis

David Wallace
Oxford

I revisit the role of a “low-entropy” past hypothesis in statistical mechanics, and argue that contrary to an apparently-widespread view, (i) the asymmetry in boundary conditions required for statistical mechanics to be derived is not well understood as an entropy constraint; (ii) it is misleading to see the high level of uniformity of the early Universe is a “low-entropy source” for present thermodynamical non-equilibrium.

Metaphysics of Laws & Time in Cosmology

Barry Loewer
Rutgers

While physicists make proposals for what the fundamental laws and objective probabilities are philosophers make proposals for what laws and objective probabilities are i.e. accounts of the metaphysics of laws and probabilities. In my talk I discuss a number of accounts of the metaphysics of fundamental laws and probabilities and how they relate to some issues in cosmology including the direction of time, fine-tuning, and the proposals that laws vary over time and location in the multiverse.

Testing Inflation

Christopher Smeenk
Rotman Institute of Philosophy

Cosmologists have often debated whether inflation is “falsifiable.” Arguments that inflation is not falsifiable typically emphasize the enormous variety of inflationary models, with differing observational signatures, or the difficulty of extracting any predictions from eternal inflation. These debates reflect disagreements about the meaning of “falsifiability” and whether it is a legitimate demand. I will argue that the empirical success of inflation can be more clearly evaluated based on the extent to which observations provide independent, overlapping constraints on the theory. Based on this approach, I will then re-assess the challenges to establishing whether inflation occurred.

Quantum Mechanics in Large Universes

Sean Carroll
Caltech

Modern cosmological models often invoke periods of quasi-de Sitter evolution, either in the past (inflation) or the future (dark energy). Quantum fields in de Sitter space evolve to a stationary vacuum state with a finite temperature. Quantum fluctuations in such a background have a number of consequences — some desirable (inflationary perturbations), some undesirable (Boltzmann Brains), and some that depend on taste (eternal inflation). I will argue that decoherence, or the lack thereof, is especially important in discussions of de Sitter fluctuations, since there are no external observers interacting with the system. In particular, I will argue that Boltzmann Brain fluctuations are not actually “real,” since they don’t decohere; inflationary density perturbations become real at reheating, while eternal inflation is a more difficult issue.

A Beginner’s Guide to Cosmological Speculation

Luke Barnes
Sydney Institute for Astronomy

Cosmologists will only ever get one horizon-full of data. Our telescopes will see so far, and no further. We also face the inevitable energy limitations of our particle accelerators. And yet, it would be an unnatural constraint on our theories for them to fall silent above a certain energy, and for there-be-dragons just beyond the edge of the observable universe. How do we speculate beyond current data? Such speculation will be invariably probabilistic, and so will test the foundations of probability theory

and scientific inference more generally. I will outline a Bayesian approach to extending physical theories, and apply this approach to attempts to explain the fine-tuning of the universe for intelligent life.

Bohmian Mechanics and Cosmology

Ward Struyve
Rutgers

Bohmian mechanics is an alternative to standard quantum mechanics that solves the conceptual problems such as the measurement problem that plague the latter. I will summarize some recent results concerning the application of Bohmian mechanics to quantum cosmology. The first is the development of an alternative semi-classical approximation to quantum gravity. The second concerns the question of space-time singularities.

On Probability and Cosmology

Martin Sahlen
Oxford

The validity of typical applications of conventional statistical theory, e.g. Bayesian statistics, to questions concerning global properties of the observable Universe, or properties of the Multiverse, is debatable. This can affect conclusions in both parameter estimation and model selection, and begs the question what an empirically based scientific method means in this context. Some relevant issues will be highlighted, and possible approaches to address them suggested.