ON THE PHILOSOPHY OF COSMOLOGY

George Ellis

ABSTRACT

This paper is an overview of significant issues in the philosophy of cosmology, starting off by emphasizing the issue of the uniqueness of the universe and the way models are used in description and explanation. It then considers successively, basic issues (limits on observations, the basic programme, major questions in cosmology); testing alternatives; testing consistency; and implications of the uniqeness of the universe. It goes on to look at multiverses and the anthropic issue, in particular considering criteria for a scientific theory and justifying unseen entities, as well as the relation between physical laws and the natures of existence. In particular it emphasizes the existence of both physical and non-physical entities, limits on our knowledge of the relevant physics ("the physics horizon"), and the non-physical nature of claimed infinities. The final section looks briefly at deeper issues, commenting on the scope of enquiry of cosmological theory and the limits of science; limits to models; physical determinism and life today; possibility spaces and the nature of causation; and ultimate causation and existence.

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George Ellis
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1. INTRODUCTION

Philosophy underlies our approaches to cosmology, even though it is usually just taken for granted and so not often explicitly explored. The core issue for the philosophy of cosmology[1] is,

"***What constitutes an explanation in the context of cosmology***? "

This has several specific aspects:

- What kinds of things are we trying to explain? What kinds of questions do we want our models to solve?
- Can we explain *what is*, by asking *what else could be the case*?
- How do we restrict explanatory models in cosmology when they are underdetermined by the data?
- How do we test if the kinds of explanation we are offering are valid?

The answers depend crucially on our investigation framework:

- ***Do you want to tackle only technical issues, restricting attention to "Physical cosmology"?***, or
- ***Do you want to deal with issues of meaning as well, extending the investigation to "Big questions"?***

This is the basic underlying choice we have to make, which shapes the questions that we ask. If we do enter the latter terrain, we need to consider

- *How much of reality do our models take seriously*?

In some cases of the models used are very limited in scope, but they are being used to answer questions that are beyond their capacity.[2] Awareness of this issue may help us resist that temptation.

In any case we should remember that "philosophical considerations are necessarily part of the physics enterprise" (Zinkernagel 2011). Even when dealing with apparently purely technical issues, there will be philosophical assumptions underlying what we are doing.

1.1 UNIQUENESS OF THE UNIVERSE

The underlying basic problem in studying cosmology is the uniqueness of the universe (McCrea 1953, Munitz 1986, Ellis 2006). There is only one object to look at, and no similar objects to compare it with. Also there is no chance to rerun it in an experiment. This is what makes cosmology unique as a science, and underlies most of the problems discussed below. It is a unique historical science, where no direct experiments are possible on the object being investigated as a whole (although many are possible on parts or aspects of the whole.)

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[1] See for example Munitz (1962), Ellis (2006), Zinkernagel (2011), Butterfield (2012).

[2] See commentary at http://edwardfeser.blogspot.com/2012/01/maudlin-on-philosophy-of-cosmology.html

It is for this reason that we have to be exceptionally careful in analyzing the relation between data and models. We need to extract all the evidence we can, and check our models in all possible ways. Additionally, this uniqueness has implications for explanation and how we understand the nature of laws and chance in this context. These specific implications will be discussed in Section 5.

1.2 USE OF MODELS IN DESCRIPTION

Explanation depends on our ideas of what exists, so is initially preceded by descriptive models based on observations; but these will then include descriptions of causal factors as envisaged by explanatory models, so the descriptive and causal models will not be independent. In any case, models of any physical system are always an idealization: they include some items while excluding others. The question "How accurate are they?" depends on the kind of question we wish to answer. So the first issue is,

1. *What kinds of things will they describe*?

If the aim is just to deal with physical cosmology, the kinds of entities are fairly obvious (geometry, matter, fields). But then the issue is,

2. *How general will they be*?

The majority of models used in cosmology are perturbed Friedmann-Lemaître-Robertson-Walker (FLRW) models. But if one wants to explore the whole range of models consistent with observations, or the range of possibilities that are the framework for what actually exists, this will not be enough (as I discuss below).

Each model has a domain of validity in terms of what it includes and what it excludes; these should be stated clearly, and not exceeded when it is used n explanatory mode. In particular, there are always hidden averaging scales in physical descriptions. One should consider,

3. *What scales of description are included? What detail will they encompass*?

The further core issue is,

4. *How will the proposed models be tested*?

Many models used in cosmology make major claims about unobservable entities and regions. An issue we pursue below is to what degree such claims can be called scientific.

1.3 USE OF MODELS IN EXPLANATION

But our models go beyond description: they aim at explanation. So the issue here is,

1. *What kinds of causation do we envisage in cosmology*?

There are obvious astrophysical kinds of causation here. But cosmological claims often go further than that: they try to explain the very existence of the universe. The kinds of causation envisaged here test the limits of science. So a key issue is, What are the limits of our causal models? How far do we take explanation? Each causal model has a domain of validity - which should be stated clearly and not exceeded. We will be able to use testable physics up to some point, but after that we will be in the domain of speculation. A further key issue therefore is

2. *To what degree are our proposed causal models testable*?

Exploring the limits will necessarily at least to start with involve presently untestable proposals, but the problem arises if they will be in principle untestable for ever. Their status as scientific explanation will then be in question – no matter how attractive they may be from some specific philosophical viewpoint.

And as in the case of description, causal models will never be complete: they will always omit some part of the causal nexus, *inter alia* because that involves all scales from the smallest to the largest – and as indicated in the last section, we cannot fully represent all the causal variables at play, let alone the interactions between them. Our models will represent some causal influences but not all. So as always

3. *Don't confuse causal models with reality*!

They will always of necessity be partial descriptions of the whole. One should respect their limits.

1.4 EPISTEMOLOGY AND ONTOLOGY

As in all cases of scientific explanation, in cosmology we are relating knowledge to an external reality, and the key scientific requirement is to test those models against what is actually out there by observational and experimental means. But our observational access to the vast distant domains of the universe is strictly limited. This means that our model building is underdetermined, because access to data is restricted in three crucial ways.

Firstly, as we look to distant domains in the universe, we see what is there through photons that travel towards us at the speed of light; so we can't see things as they are today, we only get data about things as they were in the past. To understand what things are like today, we have to extrapolate from the observable past to the unobservable present; and that is a model-dependent exercise.

Secondly, as we peer back into the past, because the observable part of the universe has been in existence only for a finite time, there are particle and visual horizons limiting our causal and visual contact with distant domains. We can only see out to matter that is presently about 42 billion light years distant;[3] the rest is unobservable for ever, except perhaps by means of cosmological neutrinos and gravitational waves – both of which are extraordinarily difficult to detect. And their scope too is limited by associated horizons. We will never have access to data about most of the universe (except if we live in a `small universe', discussed in Section 3.1 below; but this is probably not the case).

Thirdly, we are also faced with a physics horizon – a limit to our ability to test the physics relevant to understanding processes in the early universe. Hence there are profound limits on our ability to test physically explanations of what was going on then.

These three limitations will necessarily be central to any study of epistemology of cosmology; they will be very apparent in the discussion that follows.

Finally one must as always take selection and detection effects into account, asking what exists that we cannot see? What do we not detect? These are crucial in determining what we actually "see" and measure.

[3] This is three times the Hubble scale distance; that factor is because the universe is expanding. See Ellis and Rothman (1993)

1.5 PHILOSOPHY AND COSMOLOGICAL ISSUES

Because of these limits of observability and testability, as emphasized by Jeremy Butterfield (2012), our cosmological models are underdetermined by observations: we have to make theoretical assumptions to get unique models, both as regards physics and geometry. That's one reason why philosophy is inevitable in the study of cosmology: even if this is not often explicitly recognized, it's part of the territory, even in studying purely physical cosmology. And even with as much data as one would like, and even if one could use this to fix our cosmological model uniquely, we would still be left with the task of *interpreting* this model. Even if underdetermination could be eliminated at the model level, this does not imply that there is no underdetermination at the level of interpretation - i.e. about what the model implies for our understanding of the world (see Section 2 of Zinkernagel 2011).

Of course this is much more apparent in tackling foundational issues and "big questions", which go beyond purely physical cosmology (both are considered below). Proclaiming that philosophy is useless or meaningless will not help: cosmologists necessarily to some degree indulge in it, whether they acknowledge this fact or not. Poorly thought out philosophy is still philosophy, but it is unsatisfactory. Rather than denying its significance, we should carefully consider the philosophy-cosmology relation and develop a philosophy of cosmology of adequate depth.

2. UNDERSTANDING COSMOLOGY: BASIC ISSUES

2.1 LIMITS ON OBSERVATIONS

Not only is no direct experiment possible on the whole, or observations of similar entities; additionally, because of its vast scale, our ability to examine the nature of the one universe in which we exist is very restricted.

In effect we can only see the universe from one spacetime event: "here and now" (see Figure 1). All we can see (on a cosmological scale) lies on a single past lightcone; hence our cosmological models are underdetermined by possible observations: we have to make theoretical assumptions to get unique models, both as regards physics and geometry. The observational situation is shown in Figure 1.

Insert Figure 1: The basic observational situation

Conformal coordinates are used so that fundamental world lines are vertical lines, surfaces of homogeneity are horizontal planes, and null cones are at $\pm 45^{o}$. Spatial distances are distorted but causal relations are as in flat spacetime. The start of the universe is at the bottom. The universe was opaque until the Last Scattering Surface (LSS), where radiation decoupled from matter, and propagated freely from then on as cosmic black body radiation, nowadays peaked in the microwave region at 2.75K. Our world line is at the centre of the diagram; the present event "here and now" is about 14 billion years after decoupling. We see a distant galaxy at the instant it crosses our past light cone.

All events before the LSS are hidden from our view. As the LSS is where the freely propagating cosmic microwave background (CMB) originates, it contains the CMB 2-sphere we see when we measure temperature fluctuations in the CMB across the sky (Figure 2). The matter we see in this way is the furthest matter we can see by any electromagnetic radiation; hence it forms the visual horizon.

The Hot Big Bang (HBB) epoch is from the end of inflation (extremely soon after the start of the universe) until decoupling at the LSS. Nucleosynthesis took place shortly after the start of the HBB epoch, and determined the primordial abundance of light elements in our region, which we can estimate from nearby stellar spectra.

Insert Figure 2: CMB 2-sphere

2.2 THE BASIC PROGRAMME

The basic program relies on two elements: seeing what is there (based in numerous observations deriving from new telescopes) and fitting parametrised perturbed FLRW models to this data. These models involve theory: causal models give physics explanations of the dynamics, through applying the Einstein field equations with suitable matter models. Note that one fits the parameters of both the background model and of the perturbation spectrum for different matter components; one is modeling what matter is here now, and how it got there.

The basic ingredients of the resulting concordance model (Harrison 2000, Silk 2001, Dodelson 2003, Ellis 2006, Ells, Maartens and MacCallum 2012) are,

- An inflationary era prior to the hot big bang stage, including generation of a seed perturbation spectrum;
- The end of inflation, reheating, and baryosynthesis;
- The Hot Big Bang epoch, including neutrino decoupling, nucleosynthesis and baryon acoustic oscillations (BAO),
- Decoupling of matter and radiation;
- Dark ages followed by structure formation;
- Existence of Dark matter, dominating gravitational dynamics at galactic to cluster scales;
- Existence of Dark energy, dominating cosmological scale gravitational dynamics at late times.

2.3 MAJOR QUESTIONS

A series of major questions arise as regards the concordance model.

1. What are the cosmological parameters?
A series of parameters characterize the standard cosmological model, and determine

important aspects of its nature (Tegmark, Zaldarriaga, and Hamilton 2001; Dodelson 2003, Spergel et al 2006). Massive new data sets are being collected that will refine them and decrease uncertainty as to their values. An important issue is how to break degeneracies, which has been well studied (Howlett et al 2012).

2. Is the universe open or closed?
One key issue is whether the universe is open or closed, which actually is really two questions: (i) Is the spatial curvature parameter ***k*** positive, negative or zero? (ii) is the topology of the spatial sections in the universe the `natural' simply connected topology, or something more complex?

The first issue can be determined by sufficiently sensitive astronomical observations, determining the parameter $\Omega_k = k/a^2$; if ***k*** is positive, the universe has finite spatial sections if its geometry continues unchanged outside our past null cone. The second issue will not be determinable unless we live in a `small universe' (see Section 3.1 below). The value of ***k*** is also key in the dynamics of the universe: for example it determines if a bounce is possible in the past, and recollapse in the future.

3. What do they tell us about inflation?
The values of these parameters determine the ratio of tensor to scalar perturbations, and so give key information about the nature of inflation (Bond et al 2004, Ma et al 2010). They also test alternatives to inflation (Brandenberger 2009), but this is difficult because inflation is not a specific well defined theory: a large variety of alternative proposals create a lot of flexibility in what is possible, so it is difficult to disprove the whole family.

4. How did structure formation take place?
Key elements of structure formation are understood: quantum perturbations generated in inflation lead to small inhomogeneities that generate baryon-acoustic oscillations leading to inhomogeneities on the last scattering surface, which then act as seeds allowing gravitational instability to generate structure in a bottom-up way after decoupling. But the details are unclear, particularly because as non-linearity sets in, complex astrophysical processes occur associated with reheating of matter.

Additionally, an important issue is unresolved: we have the whole quantum-to-classical transition to account for, that is, how does quantum uncertainty give way to classical definiteness in the inflationary era? Current decoherence-based approaches to this question are insufficient to resolve the issue; this must necessarily involve some resolution of the measurement issue in quantum theory (see Sudarsky 2011 and references therein). This is a major lacuna in the physical explanation of structure formation in the early universe.

5. What is the nature of dark matter?
We know that dark matter is non-baryonic, but do not know what it is; however potential candidates abound. Experimental and observational searches are under way to determine its nature.

6. What is the nature of dark energy?
Existence of dark energy is established by observations of Type Ia supernovae, BAO, weak gravitational lensing, and the abundance of galaxy clusters. Particularly, decay of supernovae in distant galaxies provides a usable standard candle (maximum brightness is correlated to decay rate) that with redshifts gives a reliable detection of non-linearity in the redshift-distance relation, showing the universe is *presently accelerating*. Consequently cosmological dynamics is presently dominated an effective positive cosmological constant, with $\Omega_\Lambda \sim 0.7$. But its nature is completely unknown, indeed simple estimates of vacuum energy give the wrong answer by at least 70 orders of magnitude (Weinberg 1989). This is a major perplexity facing theoretical physics.[4] One possible resolution is some form of unimodular gravity, leading to a trace-free form of the Einstein equations (see Ellis, van Elst, Murugan, and Uzan 2011).

7. What happened at the start of the universe?
It seems that there was a start of some kind to the present expansion epoch of the universe (as it is not in a steady state). What was the nature of this start? How did it happen? (insofar as we can meaningfully ask that question).

3. TESTING ALTERNATIVES

It is general principle that one only fully understands what exists if you have a good idea of what does not exist: you don't understand the model you have unless you understand the alternatives. One should therefore ask,

What else could be the case?,

in order to understand what is.

This is particularly true in the case of cosmology, where one can't go out and examine other physical examples of universes: one can however consider other hypothetical universes, and ask why they don't exist rather than the specific one we in fact happen to live in. In particular, different models may explain the same data – there is a degeneracy in parameters with the same observational outcomes, for example - and we need to examine all the family that can explain the same data, in order to decide between them. It is not good enough to choose the first model that fits the data, when there may be many.

3.1 ALTERNATIVE TOPOLOGIES

FLRW models can have closed finite spatial sections with complex topologies even if $\boldsymbol{k}$=0 (locally flat) or $\boldsymbol{k}$ = -1 (locally negatively curved) (Ellis 1971a). While in general we can't tell what the topology of the spatial sections is, because they extend beyond our visual horizon, there is one exceptional case: we might possibly live in a "small universes" with closed spatial sections where the closure scale is less than the size of the visual horizon (Ellis and Schreiber 1986, Lachieze-Ray and Luminet 1995). In that case we can see right round the universe since decoupling, and can see many images of the same galaxy at different times in its history– including our own. Local physics will be the

[4] It is not however the most important problem in science, as some have claimed.

same as in the usual models, but there will be a large-scale cut off in wavelengths because of the compact topology.

This is an attractive scenario in various ways, because these are the only cases where we can see the entire universe (Ellis and Schreiber 1986); but is quite difficult to test observationally. However it is in principle testable by source observation and by checking for identical circles in CMB sky (Cornish, Spergel, and Starkman 1998). Many simple cases have been excluded through such observations, but there remains a small possibility it may be true. If so it would be a major feature of the observed universe. It is a possibility that should indeed be fully observationally tested.

3.2 ANISOTROPIC (BIANCHI) MODES

Another question is what difference can anisotropy make to dynamics and observations? This has been extensively investigated through use of the Bianchi spatially homogeneous but anisotropic models (Wainwright and Ellis 1996). Using such models one can put observational limits on early universe anisotropy, particularly by studying CMB anisotropies and element production in such universes.

There is no evidence at present that there were indeed significant such anisotropies. But the point there is that one can't ask these questions unless you have such models. Indeed it is ironic that most papers on inflation say it can solve anisotropy and inhomogeneity issues, but only consider FLRW models. You can't derive that conclusion on this basis.

3.3 DARK MATTER AND MODIFIED GRAVITY

One of the key issues is that dark matter is predicted to exist on the basis of astronomical observations, but is not yet understood. It is crucial to check that these observations do indeed indicate existence of dark matter, rather than that our theory of gravity is wrong.

Consequently it is important to investigate alternatives such as MOND – modified Newtonian dynamics, and its GR versions (Bekenstein 2012). There are a variety of such models, but they are restricted in various ways (Starkman 2012) One should note here that we get evidence on dark matter from gravitational dynamics in galaxies and clusters, from structure formation studies, and from gravitational lensing observations. Any theory must handle all these aspects.

3.4: DARK ENERGY AND INHOMOGENEITY

One of the major problems for cosmology, and indeed theoretical physics, is the unknown nature of dark energy causing a speeding up of cosmological expansion at recent times (Weinberg et al 2012): Is it a cosmological constants? Is it "quintessence" (some dynamical form of matter?). What else might it be? And how are the observations compatible with estimates of the energy density of the quantum vacuum, some 70 to 120 orders of magnitude larger than the observed energy density? (Weinberg 1998)

Again one needs to investigate the possibility that the observations test a breakdown in General Relativity Theory rather than existence of dark energy, and many investigations are under way considering possible modifications of GRT that could account for the observations, such as including higher order terms in the Lagrangian. But given the significance of the problem, one needs to explore all possible other routes for explaining the observations.

It is therefore of considerable importance that there are geometrical models that in principle can explain the data without any need for any modification of gravity, or any exotic physics. Because we observe spherical symmetry around us to high accuracy, we need to use spherically symmetric (Lemaître-Tolman-Bondi) models where we are somewhere near the centre. Now many people don't like this philosophically, but that's too bad: if the observations say that is the way things are, we have to accept it, and adjust our philosophy to fit the facts.

So can we observationally put limits on late universe inhomogeneity? Can we test the Copernican Principle (the assumption we are at a typical place in the universe) rather than taking it as an untestable philosophical *a priori* assumption? Can we do away with dark energy through inhomogeneous models?

The answer is that in principle this is indeed all possible. The SN data could be revealing inhomogeneity violating the Copernican Principle on close to Hubble scales. Such models are able to explain the SN observations: that's a theorem (Mustapha, Hellaby and Ellis 1999). So can such models explain the rest of the data of precision cosmology? Maybe, maybe not. A variety of tests have been developed based on

- ***Supernova observations*** down the past null cone (Clarkson, Bassett and Lu, 2007),
- Relating ***CBR anisotropies*** and ***BAO measurements*** in such models (Clarkson and Maartens 2010),
- Based on the ***kinematic Sunyaev-Zeldovich*** effect (Clifton, Clarkson and Bull, 2012).

The latter test in effect enables one to see the interior region of the CMB 2-sphere on the LSS (see Figure 3) because of the scattering of radiation by hot gas that underlies the kSZ effect. Thus it in essentials is an observational implementation of the `almost-EGS theorem' (Stoeger, Maartens and Ellis 1995) that proves a FRW geometry exists if the CMB radiation is almost isotropic everywhere in an open neighborhood of a point.

Insert Figure 3 here: Testing homogeneity via the KSZ effect

Another possibility is

- ***Uniform Thermal Histories***: Testing that distant matter we observe has the same thermal history as nearby matter, resulting in the same kinds of structures being formed in distant regions as nearby (Bonnor and Ellis 1986).

Tests of distance element abundances fall in this category (see Section 4.5 below).

Now some people claim these tests are unnecessary: it is philosophically implausible we live in such a universe, and so a waste of time checking the Copernican (homogeneity) principle. I completely disagree. A set of testable alternatives exists, leading to interesting observational proposals; it is important to do these tests, both because the CP is the foundation of standard model, and if it is not valid one can possibly do away with need for Dark Energy – one of the key mysteries in present day cosmology.

These tests have the effect of turning a previously untested *a priori* philosophical assumption at the foundations of standard cosmology into a scientifically testable hypothesis. I regard that as a big step forward: it is good physics and good science. Philosophical assumptions may or may not be true: we should test them whenever we can**.**

4 TESTING CONSISTENCY

These tests can be regarded as consistency tests for the standard model. Because of the uniqueness of the universe as discussed above, consistency tests are of crucial importance: we should check our models for consistency in all possible ways (a philosophical point with implications for scientific practice). I list here further such tests.

4.1. AGES: IS THE UNIVERSE OLDER THAN ITS CONTENTS?

This is perhaps the most crucial test of all: if it comes out wrong, it has the capacity to destroy the standard model. Indeed this is Hubble never believed in the idea of an expanding universe: the value of the Hubble Constant that he attained was wrong, and this test came out inconsistent with the FLRW models of his time. With present Hubble constant estimates, this works out acceptably. But it is crucial to keep checking as estimates of ages change.

4.2. CBR-MATTER DIPOLE AGREEMENT

The standard interpretation of the CMB dipole anisotropy is that it is due to our motion relative to the cosmic rest frame defined by the CMB. A consequence is that there must be a parallel dipole in number counts of all classes of astronomical objects: radio sources, for example (Ellis and Baldwin 1984). If this dipole agreement were not to exist, it would call into question the cosmological interpretation of either the relevant sources, or the CMB. It would undermine the whole of the standard model if the CMB were not of cosmological origin (as suggested for example by the quasi-steady state theory). The sensitivity and statistics are difficult, but it seems this test is Ok.

4.3. COSMIC DISTANCE-DUALITY RELATION

A key feature of standard models is the cosmic distance duality relation, also known as the reciprocity theorem (Ellis 1971). This underlies the standard (M,z) relation, CMB intensity observations, and gravitational lensing intensity observations. If it were not true, then the foundational assumption that observations are based on photons moving on null geodesics in a Riemannian spacetime would be proved wrong.

Tests are indeed possible, for example Khedekar and Chakrabort (2011) report one based on HI mass functions, and Holanda, Goncalves, and Alcaniz (2012) propose a test using measurements of the gas mass fraction of galaxy clusters from Sunyaev-Zeldovich and X ray surface brightness observations. They find no significant violation of the distance-duality relation.

4.4. CBR TEMPERATURE AT A DISTANCE

If the standard interpretation of the CMB is right, its temperature must change with redshift according to the formula $T(z) = T_0\,(1+z)$. Hence we need to find distant thermometers to measure the CMB temperature at significant redshifts. One such thermometer is interstellar molecules (Meyer 1994); it turns out one can also use the Sunyaev Zeldovich effect to test this relation (Avgoustidis et al 2011).

This again is an important test: it checks that the CMB is what it is believed to be, rather than some local effect. So far this too is working out OK.

4.5. PRIMORDIAL ELEMENT ABUNDANCES WITH DISTANCE

If the universe is spatially homogeneous then element production must also be spatially homogeneous, so primordial element abundances for galaxies at high z should be the same as nearby. This seems to be the case, although there is some query as regards Lithium; if that problem persists, it could be an indication of an inhomogeneous universe (Regis and Clarkson 2010). The importance of this test is that it checks conditions at very early times – long before the LSS – far out from our world line (see Figure 4). This is a special case of tests of uniform thermal histories for distant matter (Section 3.4).

Insert Figure 4 here: Nucleosynthesis far out is tested by primordial element abundances.

5 THE UNIQENESS OF THE UNIVERSE

As mentioned in Section 1.1, the key feature that separates cosmology from all other sciences is the uniqueness of the universe. There is only one object to look at; there is no similar object to compare it with. We can of course investigate almost countless aspects of the universe; but they are all aspects of one single object, the single universe domain we can observe. It's not just that we can't observe other universes: we also can't experiment on other universes, nor rerun this one. We have one unique object with one unique history that we want to understand. No other science has this nature. It is at this point that we inevitably move from more technical issues to more philosophical ones.

5.1 THE PHILOSOPHY OF THE HISTORICAL SCIENCES

Now there are many other historical sciences (for example, the origin of the Galaxy, the origin of the Solar System, and the origin of life on Earth), and the way they relate to theory is different than the experimental sciences, which is why they are often so much more controversial. But in all the other cases there are at least in principle other examples we can consider and about which we can one day hope obtain data (the most difficult example being the origin of life, but that may have occurred elsewhere in the universe. This is not the case as concerns cosmology. It is the unique historical science: hence we need to extract all evidence we can, and check our theories in all possible ways, as discussed above. But there are further consequences we now look at.

The issue in all historical sciences *is the tension between general laws and specific applications*: how does one relate the influence of universal aspects (necessity) to that of contingent events (chance)? What is the role of specific initial conditions, as against that of general laws of universal validity? This leads to the question

- Is chance a genuine causal category, or is it just a code word for the fact that although everything is fully determined, we just don't have the necessary data?

It is often treated as if it is a genuine causal factor, as in Monod's famous book *Chance and Necessity* (Monod 1972), but this is a very strange concept of a cause. Not knowing what the cause is, is not a very compelling cause! But this is to do with the issue of emergence of higher levels of structure, with coarse graining leading to a loss of lower level information (see section 8.2); in that context it can be regarded as a valid type of causation, because we have a level of description which excludes detailed lower level information. However in cosmology one is trying to model all there is; is it legitimate in that context? This is crucially tied in to the issue of the scale of modeling, mentioned above; but it also relates to the issue of determination by unique initial data, rather than generic laws

Chance as a "causal category" is discussed by Hoefer (2010). Epistemologically there is really not a problem – there "chance" just stands for causes we are unable to discern or determine. We don't know enough. Apparently, however, some philosophers in the past (e.g. Thomas Aquinas) considered ontological chance as a genuine causal category.[5]

The specific situation where this matters is the idea of *cosmic variance:* the difference between what our statistical set of models predicts, and the specific unique outcome we actually encounter. In particular, the observed CBR angular power spectrum is significantly lower at large angles than predicted by theory. The issue is whether this large angle discrepancy between theory and observation is in need of an explanation, or is it just a statistical fluke due to "chance" that needs no explanation? This is a philosophical question that gains a bit of bite because just such a cut-off at large angular scales is predicted to occur in "small universes" (Section 3.1 above). The usual assumption is that it's just a statistical fluke. Starkman et al (2102) discuss other such anomalies in the CBR observations.

[5] I thank Bill Stoeger for comments on this issue. Quantum theory raises specific issues in this regard I will not consider here.

The deeper issue in this regard is the common assumption that the universe should not be "fine tuned": it is taken for granted that it should in some sense be of a generic nature. This is a complete philosophical change from what was taken for granted in cosmology up to the late 1970's: before then it was taken for grated the universe had a very special nature. This was encoded in the idea of a *Cosmological Principle*, taken as a foundational presupposition of cosmology (Bondi 1960). The pendulum has swung to the opposite extreme, with people searching for all sorts of explanations of "fine tuning". But no physical law is violated by any fine tuning there may be. Improbability of existence of fine tuning is a perfectly valid argument as regards multiple entities that occur in the universe and are subject to statistical laws; but there is no possible evidence or proof that the universe itself is subject to any such laws. So a key philosophical question is,

- ***Is the universe probable***?

This is an untestable philosophical assumption underlying much present day work, presumably based in the idea of probability in an ensemble of possibilities. But if only one universe is realised, this ensemble is hypothetical rather than actual, and there is no conclusive reason that it should be probable: the requisite ensemble for that argument does not exist. Maybe the universe IS fine tuned! - indeed there is a lot of evidence this is indeed the case (see the discussion of the Anthropic Coincidences below.)

Whatever one's attitude, one should recognise that the concept of fine tuning is a philosophical issue. This illustrates how cosmology is a unique topic in physical science.

5.2 LAWS AND INITIAL CONDITIONS

The further key point arising is that because of the uniqueness of the universe, it is not clear how to separate "Laws" (generic relations that must always be true) from initial conditions (contingent conditions that need not be true). Given the unique initial conditions that occurred in the one existing universe,

- We don't know what aspects of those initial conditions had to be that way, and what could have been different.
- Some relationships that locally appear to us to be fundamental physical laws my rather be the outcome of specific boundary or initial conditions in the universe: they could have worked out differently.

The prime example is the existence of the second law of thermodynamics with a specific uniquely determined arrow of time. No choice of the arrow of time is determined by local fundamental physical laws, which (with one very weak exception) are time symmetric. It seems to be common cause nowadays that the unique one-way flow of time embodied in the crucially important second law of thermodynamics (Eddington 1928) is not after all a fundamental physical law: it is due to special initial conditions at the start of the universe (Ellis and Sciama 1972, Carroll 2010, Penrose 2011). Another example is the claim that the constants of nature – fundamental determinants of local physics (Uzan 2011) -- are determined by the string theory landscape, and so may vary from place to place in the universe. On this view, local physics is variable and context dependent (Rees 1999, Susskind 2006). Effective physical laws are then only locally valid (although determined by an underlying scheme that is globally valid). This is one of the drivers for searches to see if the constants of nature may vary with position in the universe (Uzan 2011).

It must be emphasized that neither of these propositions can be proven to be the case; but certainly the first is widely believed as an outcome of tested physics, while the second is taken by many as being implied by plausible extrapolations of known physics.

6 MULTIVERSES: DENYING THE UNIQUENESS OF THE UNIVERSE

One response to this situation is to deny the uniqueness of the universe: to claim we live in a multiverse (Carr 2009). Various motivations are given for this proposal:

1. It is claimed as the inevitable outcome of the physical originating process that generated our own universe, e.g. as an outcome of the chaotic inflationary scenario or of the Everett interpretation of quantum theory.
2. It is proposed as the result of a philosophical stance underlying physics: the idea that "everything that can happen happens" or "whatever is possible is compulsory" (the logical conclusion of the Feynman path integral approach to quantum theory).
3. It is proposed as an explanation for why our universe appears to be fine-tuned for life and consciousness, giving a probabilistic explanation for why we can exist.

While the first is often claimed, it is the latter that has the most philosophical oomph.

6.1 FINE TUNING: THE ANTHROPIC ISSUE

Examination of theoretically possible alternative universe models shows that there are many very specific restrictions on the way things are that are required in order that life can exist. "The universe is fine-tuned for life", both as regards the laws of physics and as regards the boundary conditions of the universe (Barrow and Tipler 1986).

A multiverse with varied local physical properties is one possible scientific explanation of this apparent fine tuning: an infinite set of universe domains with varying physics may allow almost all possibilities to occur, so that somewhere things will work out OK for life to exist just by chance (Rees 1999, 2001, Susskind 2006, Weinberg 2000, Carr 2009). Note that it must be an ***actually existing*** multiverse for this to work: this is essential for any such anthropic argument.

As a specific example of the genre is *Just Six Numbers* by Martin Rees (1999). He explains that in order that life can exist, there must be fine tuning of the following physical constants:

1. *N = electrical force/gravitational force $=10^{36}$*
2. *E = strength of nuclear binding = 0.007*
3. *Ω = normalized amount of matter in universe = 0.3*
4. *Λ= normalised cosmological constant = 0.7*

5. Q = seeds for cosmic structures = 1/100,000
6. D = number of spatial dimensions = 3

He explains (Rees 1999),

> "*Two of these numbers relate to the basic forces; two fix the size and overall 'texture' of our universe and determine whether it will continue for ever; and two more fix the properties of space itself… These six numbers constitute a 'recipe' for a universe. Moreover, the outcome is sensitive to their values: if any one of them were to be 'untuned', there would be no stars and no life… An infinity of other universes may well exist where the numbers are different. Most would be stillborn or sterile. We could only have emerged (and therefore we naturally now find ourselves) in a universe with the 'right' combination. This realization offers a radically new perspective on our universe, on our place in it, and on the nature of physical laws*."

Note that this assumes the basic structure of physics is unchanged; it is only the constants of physics that vary. This is a minimalist approach to the idea "almost all possibilities occur": generically this could be much more broad (Tegmark 2004). What one assumes as possible is a philosophical choice, with no physical or observational test possible of whatever assumptions one makes.

Rees focuses on only six parameters, but there are in fact many other physical constants that must be fined tuned if life is to be possible (Barrow and Tipler 1986, Ellis 2006). The particular important application of this idea is to explaining the small value of the cosmological constant ("dark energy") by such an anthropic argument (Rees 1999, Weinberg 2000, Susskind 2006). Too large a positive value for Λ results in no structure forming and hence no life being possible; too large a negative value results in recollapse, with too short a lifetime for the universe to allow life to emerge. Thus anthropic considerations in a multiverse where Λ takes all possible values require that the value of Λ we observe will be small (in fundamental units), thus justifying the value we observe --- different by 120 orders of magnitude from the value of the vacuum energy predicted by quantum field theory (Weinberg 1989). It provides a scientific explanation of this otherwise extremely implausible value.

This example makes clear the true multiverse project: making the extremely improbable appear probable. It is a potentially viable explanatory model of such fine tuning in the universe domain we inhabit and observe.However even if a multiverse is assumed to exist, it is not clear that a meaningful probability measure is available, nor is it clear that that an infinite universe necessarily allows for all possibilities to occur (for a discussion, see Section 4.1 of Zinkernagel: 2011). The prospects for a viable explanation in probabilistic terms in this way are not fully secure.

6.2 TESTABILITY

The key observational point however is that all the other domains considered in multiverse explanations are beyond the particle horizon (depicted in Figure 1) and are therefore unobservable. These observational limits are made clear in Figure 5. The assumption is we that can extrapolate from the observed domain to 100 Hubble radii, 10^{1000} Hubble radii, or much much more: the word `infinity' is casually tossed around in these writings, so that if we could see to $10^{10,000,000}$ Hubble radii we would not even have started testing what is claimed -- and we can only see to 42 billion light years.

Now this is an extraordinary claim. It is an explanation whose core feature is the assumption of huge numbers of entities as large as the entire visible universe that are in principle unobservable. The idea is that the theory (anthropic explanation of Λ in this way) is so good you should not worry about the basic causal feature of the theory being completely untestable.

However some claim such a multiverse is *implied by known physics,* which leads to chaotic inflation (Linde 2003), with different effective physics necessarily occurring in the different bubbles of chaotic inflation (Susskind 2006). But this is not the case. The key physics (e.g. Coleman-de Luccia tunneling or the hypothesized inflaton potential, the string theory landscape) is extrapolated from known and tested physics to new contexts; the extrapolation is unverified and indeed is unverifiable; it may or may not be true[6]. For example the parameter values that lead to eternal chaotic inflation may or may not be the real ones occurring in inflation, assuming it happened. And in particular the supposed mechanism whereby different string theory vacua are realised in different universe domains is speculative and untested.

The situation is not

$$\textit{Known Physics} \rightarrow \textit{Multiverse}, \quad (1)$$

as some writings suggest. Instead it is:

$$\textit{Known Physics} \rightarrow \textit{Hypothetical Physics} \rightarrow \textit{Multiverse} \quad (2)$$

Major Extrapolation

The physics is hypothetical rather than established! This extrapolation is untested, and indeed may well be untestable: it may or may not be correct. The multiverse proposal is not based on known and tested physics.

CAVEAT 1: A DISPROOF POSSIBILITY

There is however one case where the chaotic inflation version of the multiverse can be disproved: namely if we observe that we live in a small universe, and have already seen

[6] See for example http://blogs.discovermagazine.com/cosmicvariance/2011/10/24/guest-post-tom-banks-contra-eternal-inflation-2/

round the universe. In that case the universe is spatially closed on a scale we can observe, and the claimed other domains don't exist. As mentioned above (Section 3.1), we can test this possibility by searching for identical circles in the CBR sky. This is a very important test as it would indeed disprove the chaotic inflation variety of multiverse. But not seeing them would not prove a multiverse exists: their non-existence is a necessary but not sufficient condition for a multiverse.

CAVEAT 2: A PROOF POSSIBILITY?

The recent development of interest is the idea that proof of existence might be available through bubble collisions in the multiverse. Bubbles in chaotic inflation might collide if rate of nucleation is large relative to rate of expansion, and this might be observable in principle by causing recognisable circles in the sky, with different properties in their interior as opposed to the exterior. This is an intriguing idea, not withstanding the difficulties of predicting what would happen if spheres with different physics intersected each other. The clincher would be if one could demonstrate different values of some fundamental constants inside and outside such circles (Olive, Peloso, and Uzan 2011): that would vindicate the idea of different physics occurring in different domains, the core feature of a multiverse explanation.

However not seeing them does not disprove the multiverse idea: these collisions will only occur in restricted circumstances in some multiverse instantiations. But this is certainly worth looking for: it is the only known observational test that would give genuine support to the physics of the multiverse proposal.

6.3 CRITERIA FOR A SCIENTIFIC THEORY

Given that the multiverse proposal is not testable in any ordinary way, is it science? We need to consider what is the core nature of a scientific theory (a philosophical question). The kinds of criteria usually invoked are,

1**. Satisfactory structure**: (a) internal consistency, (b) simplicity (Ockham's razor), (c) beauty' or `elegance';

2. **Intrinsic explanatory power**: (a) logical tightness, (b) scope of the theory --- unifying otherwise separate phenomena;

3. **Extrinsic explanatory power**: (a) connectedness to the rest of science, (b) extendability - a basis for further development;

4. **Observational and experimental support**: (a) the ability to make quantitative predictions that can be tested; (b) confirmation: the extent to which the theory is supported by such tests.

It is the last two, and particularly the last, that characterizes a theory as scientific, in contrast to other types of theories that would like to be classed as scientific but are rejected by mainstream scientists, such as Astrology or Intelligent Design. Their adherents claim they all satisfy the other criteria; it is predictive observational test and experiment, as well as separation from mainstream science, that separates recognised sciences from these claimants.

Note 1: One must beware the non-uniqueness of Occam's razor and criteria of beauty. Is the multiverse idea beautiful? It depends on the eye of the beholder. Does it satisfy Occam's razor? Well one single entity (a multiverse) explains everything one wants to explain: the height of economy! But wait a minute: that one entity consists of uncountable billions of entire universe domains, each as large as the universe region to be explained, and each containing a huge number of galaxies, indeed often stated to be infinite. In this light it is a most extraordinarily extravagant postulation of innumerable unobservable "universes" – all to explain one single entity (the observable universe). It hardly can be characterized as a law of parsimony.[7]

Note 2: Our best physical theories allow various independent observations and experiments to constrain the theory. Agreement of such independent measurements of physical parameters is a much more demanding requirement than simple predictive success. Does the multiverse satisfy this criterion? No, because since it is assumed that anything whatever can happen in the various multiverse domains, a multiverse hypothesis can explain anything at all – which means you can't disprove it by any particular observation, because it does not uniquely predict anything specific.

There are some theories claiming that a multiverse predicts the universe must have open spatial sections (Freivogel et al 2006, Susskind 2006)– but that only holds for some multiverse theories. The theories are extremely malleable. Some of them are constrained to obey the supposed 10^{500} possibilities of the string theory landscape – but we don't know what these possibilities are, we don't even know if they include the physics we actually experience, and the status of this landscape proposal is disputed in the string theory community.

Note 3: One might include as a criterion the way the conclusion is arrived at: for example the openness with which it is approached and the willingness to look at alternative explanations. In Lakatos' terms, does it constitute a progressive scientific program? (Lakatos 1978). This raises very valid issues, but is hard to make precise and replicable; and while it is philosophically widely accepted, it is not an accepted criterion in the scientific community.

The multiverse program is based on downgrading criterion 4 relative to the others; this is dangerous thing to do in that this amounts to a redefinition of what constitutes genuine science, because it is at the heart of the scientific method. This opens the door for all sorts of enterprises that are presently not considered as genuine science to be reclassified as true science. Multiverse adherents also claim it is strongly supported by criterion 3; but as noted above, the areas of physics that it is strongly linked to, such as string/M theory, are

[7] Wikipedia: "In his *Summa Totius Logicae*, i.12, Ockham cites the principle of economy, *Frustra fit per plura quod potest fieri per pauciora* [It is futile to do with more things that which can be done with fewer].

speculative and unproven rather than experimentally well-established domains. These areas are fashionable but not necessarily correct descriptions of the real world.

6.4 JUSTIFYING UNSEEN ENTITIES

However a broader issue arises from this discussion:

- ***When can existence of unseen entities be justified***?

Examples are the metric tensor in general relativity theory, the electric field, dark matter, and dark energy in cosmology. What is the process of justification of thinking of these as "real"? Or should they rather be thought of as mental entities with no physical existence?

My own view is that unseen entities can be taken as real if

1. They form an essential link in a chain of argument with well supported foundations,
2. They have demonstrable predictable effects on the physical world of matter we see around us that are in agreement with experimental outcomes, and
3. There is no other possible explanation for the same phenomena.

One should test any such suggestion on a variety of possibilities: entities such as the metric tensor, the electric field, dark matter, dark energy, other people's emotions, the mind, a soul; and modify the proposal if the outcome seems unsatisfying

Do these criteria apply to the multiverse? In my view it does not satisfy 1., because the foundations are not well supported, nor 2., because the outcomes of multiverse hypothesis are not predictable, nor 3., because for example it might simply be shear chance: as stated before (Section 5.1), probability need not apply to the universe. This is where unproveable underlying philosophical presuppositions come in. The outcome depends on those assumptions.

One point of clarification here: claims have been made of probabilistic prediction of the value of the cosmological constant, similar to what is seen (Weinberg 2000). But these are statistical predictions: they have no meaning if there is only one universe. They are consistency tests of such a multiverse proposal, but cannot be taken as proofs, for they take for granted what is to be proven. They are probabilistically suggested but not sufficient conditions for existence of a multiverse.

Multiverses: The big issue

In order to explain one single entity, multiverse explanations suppose billions or even an infinite numbers of unseen and untestable entities at the same level of complexity as that to be explained. They cannot be adequately justified according to the criteria just discussed. But the very nature of the scientific enterprise is at stake in the multiverse debate: the multiverse proponents are proposing weakening the nature of scientific proof in order to claim that multiverses provide a scientific explanation. This is a dangerous tactic; and it does not solve the ultimate issues it is claimed to solve, as discussed below.

Overall the multiverse proposal is a very interesting philosophical proposal, based in speculative science. As such it is a good contribution to cosmology; but it is unproven and indeed probably unproveable; this status should be acknowledged. Belief in its correctness is just that: it is a belief. It is not established fact.

Bill Stoeger responds to this (private communication), "we cannot directly substantiate the existence of a multiverse directly, and we are not anywhere near being able to do that indirectly. However, there does seem to me to be the possibility of doing so in the distant future if some very stringent conditions on a future multiverse model are eventually fulfilled: If a particular type of multiverse model were an essential element in a well-supported theory about the origin of our observable universe and its characteristics, and that theory enjoyed long term success in bringing progressively more aspects of our universe into a coherent overall picture, and provided a basis for other fruitful advances in cosmology and physics (better than other competing theories), then, it seems to me that we could legitimately maintain scientifically that that multiverse exists. That's a long shot, I admit. But it is still a possibility. There might be a certain amount of predictive success in that long-term fruitfulness, but there might not be. However, I don't think that detailed predictability is necessarily a ``sine qua non" for an adequately tested scientific theory. We usually consider it to be the case for the physical sciences; but it has been pointed out by a number of people that it really doesn't seem to be a requirement in the biological sciences -- at least not in the same way. You do deal in some detail with this in your paper -- with three conditions for scientifically determining the existence of an unseen entity. It seems to me that, at least in principle, it is possible to fulfil all three in the case of a multiverse. There is my reservations about the necessity of predictability -- or least about the sort of characteristics or things the multiverse model must successfully predict. It certainly must ACCOUNT for all or most of those – but prediction is something different from that. I thoroughly agree with your other two conditions (1. and 3.)."

Note that we are concerned with *really existing* other universes, not potential or hypothetical one; there is no problem with them, but they cannot fulfill the desired anthropic explanatory role. It is ironic when someone on the one hand insists that the core virtue of science is testability, and on the other strongly supports existence of a multiverse in order to explain fine tuning. There is a clear disjunction here between what is claimed to be desirable and what is then in fact argued.

7: PHYSICAL LAWS AND THE NATURES OF EXISTENCE

Underlying one's view of the nature of cosmology is the issue of what kinds of entities are supposed to exist: a significant philosophical issue. Obviously one assumes existence of matter and fields, and (as we use General Relativity as our gravitational theory) of space time. But these are not the only kinds of entities we assume exist.

7.1 PHYSICAL AND NON-PHYSICAL REALITIES

As well as these physical entities, we have to assume existence of at least two other kinds of entities that are not of themselves physical.

Physical laws: Firstly we assume existence of physical laws. These are not the same as matter or fields: rather they are what shape the behaviour of matter and fields. Equivalently one can talk of the existence of ***possibility spaces*** for matter and fields (Ellis 2004): these are essentially equivalent to the laws that shape them, just as a set of equations are essentially equivalent to the set of all their solutions. These laws are not culturally determined or variable (although their specific descriptions are culturally variable). They embody the essential nature of matter, and are eternal, unchanging, and omnipresent, with their outcomes crucially shaped by the values of specific fundamental constants (Uzan 2010).

Mathematics: Secondly we have to assume the existence in some form or other of mathematics. I follow Penrose (1997), Connes (see Changeux and Connes 1998), and others in assuming mathematics is discovered rather than being invented, hence exists in some kind of eternal and unchanging form independent of matter and mind, of time and place; in brief, some kind of Platonic existence. In some mysterious way it underlies or underpins the nature of physical laws (Penrose 1997).

Now where this specifically matters is as regards the relation between the laws of physics and creation of the universe. The key issue here is,

- ***What was there pre-existing the universe?***

According to the way this is talked about by various cosmologists (e.g.Vilenkin 1982, Hawking and Mlodinow 2010, Krauss 2012), the idea seems to be that the laws of physics were somehow pre-existing entities responsible for the creation of everything physical (they themselves not being physical, as emphasized above). Somewhere somehow pre-existing the Universe there was quantum field theory, Hilbert spaces, a space of symmetry groups, Hamiltonians, Lagrangians, the Higgs mechanism, and so on; but how or where they existed is not explained. One might suppose a Platonic conception of laws assumes these to "be" outside space and time. In this case one faces the further question of how such laws manage to govern or control that which is in space and time. This may only make sense insofar as laws and the entities they govern are somehow mutually dependent, so that it becomes hard, after all, to understand the laws as "preexisting" space and time, the universe, and the stuff within it.

But these are of course laws we determine ***in*** the universe rather than being laws ***for*** the universe: this takes us back to the question,

- ***Are there laws for the universe per se***?

- they have no application except to the universe itself. As explained above this is a problematic idea: if a law applies only to one thing, it's not a law, it's a description of one specific instance: this was the nature of the `cosmological principle' that was previously assumed to underlie cosmology, see Bondi (1960).

In any case the point here is that as well as physical entities, we must assume at least the two other kinds of non-physical entities in order to make sense of the physical world.

7.2 PHYSICAL LAWS AT THE FUNDAMENTAL LEVEL

But then what is the nature of physical laws and what is the nature of their existence? This is a key metaphysical issue. There seem to be two major possibilities:

- ***Are they prescriptive***? Are the laws of physics somehow written in a Platonic space from which they control the nature of physical existence?

If so where and how do they exist? This would in some sense be a mathematical description; it would precede the existence of the universe, somehow governing its coming into being as just discussed.

- ***Are they descriptive***? The laws we love are phenomenological: they just describe what is; this is just the way matter behaves, but it is not controlled by Platonic laws. But if this is the case, why is the behaviour of matter the same everywhere? We know that electrons and photons behave in exactly the same way in completely different parts of the distant universe (this is proved by the isotropy of the CMB). What causes the behaviour of matter to be identical everywhere, if this is not enforced by prescriptive physical laws? We have no answer to this conundrum. Then there is Wigner's question

- ***Why are physical laws so well describable by mathematics?*** As mathematics describes ordered patterns of relationships, it is perhaps not surprising that these relationships and processes can be described mathematically. The very nature of mathematics is indeed to describe patterns: in space and time, and indeed in patterns (leading to recursion and higher order relations). What is however surprising is that fundamental physical relationships can often be described so accurately by very simple laws, such as an inverse square law.

My suggestion is that this is because the underlying nature of these fundamental laws is geometrical, which results in them being accurately represented by simple analytic relations. Examples are,

- 3-d Geometry and conservation of particles or fields gives an inverse square law,
- Parallel transport along curves underlies Yang Mills theory, the Aharanov-Bohm effect, and Feynman path integrals, leading to holonomy as a fundamental entity,
- Path integrals lead to geodesic paths corresponding to extremal distances, and underlie variational principles as a mathematical description**.**

So maybe the reason is that geometry underlies all physics, and not just general relativity. In any case, in some deep sense mathematics underlies physics whose core is seen by practising physicist to be calculations; and both underlie physical reality though they themselves are not physical (Penrose 1997).

7.3 THE PHYSICS HORIZON

Limits to Testability: As has already been mentioned, a key issue in our attempts to use physical laws to understand the universe in which we live is the limits to what is testable in the laboratory and in the solar system. To tackle causation in the very high energies in the very early universe, we have to extrapolate known physical laws to domains where they are untested and maybe untestable. We hit the ***Physics Horizon***: the limits on what is testable now, and on what it will ever be possible to test. Different extrapolations are possible from known and testable physics, with different outcomes.

This is relevant to the very early universe (before inflation) with the very high energies involved, hence uncertainty increases in the very early universe as testability declines. Particularly, it applies to theories of creation of the universe itself: whatever we may assume about such creation, we certainly can't test the relevant physics, pre-physics, or metaphysics (whichever controls what happens).

Of course we must explore all alternatives:

- Wave function of universe,
- Pre-big bang and cyclic cosmologies,
- Brane cosmology and string cosmology,
- Loop quantum cosmology.

But all of them are highly speculative untested physics, and most suffer from mathematical problems such as ill definition or divergences. We must test their outcomes as we can, but one must be cautious about testing them by predicted CMB anisotropies, which they all laudably strive to achieve. The basic fact is that,

$$\{A \Rightarrow B\} \text{ does not necessarily imply } \{B \Rightarrow A\}$$

CMB predictions are crucial – they are necessary for a viable theory -- but are unlikely to be sufficient to establish any specific such theory. This also applies to attempts to use the cosmological constant to prove existence of a multiverse: no specific value of Λ can either prove or disprove existence of a multiverse. They can be suggestive at most.

Extrapolation beyond the domain of validity: Another problem (which is related to, but is not reduced to testability) occurs when models are extrapolated outside the region in which their basic assumptions (and concepts) are valid. One example is the possible breakdown of the FLRW-model and its cosmic time concept if a scale-free phase is reached in the early universe (making it difficult to e.g. define homogeneity), and/or if a pure quantum phase is reached (making it difficult to define particle trajectories and hence satisfy the Weyl principle), see Rugh and Zinkernagel (2009, 2011).

The temptation to make such extrapolations is strong when we have no way of testing the outcomes, and indeed there is nothing wrong with testing such ideas out; but one must make clear they are being extrapolated beyond the domain where we can securely believe them to be valid.

Respecting known physics: There is a further key point: in trying out such speculative physical ideas, one should not just abandon basic physics constraints on what is possible, as seems to be happening more and more. Particular examples:

- one should avoid theories with a varying speed of light, unless you show how to reliably determine distances independent of light (Uzan and Ellis 2005);

- one should avoid dark energy theories with $w := dp/d\rho < -1$, unless you have a truly viable theory of how this can emerge from the underlying physics (rather then being due to negative kinetic energy), AND can explain how it won't lead to major instabilities (due to the negative inertial mass density).

Currently, there is a culture of allowing anything whatever in speculative cosmological theories – sometimes abandoning basic principles that have been fundamental to physics so far. Science writer Margaret Wertheim attended a 2003 conference on string cosmology at the Santa Barbara KITP, and reported as follows (Wertheim 2011):[8]

> *That string cosmology conference I attended was by far the most surreal physics event I have been to, a star-studded proceeding involving some of the most famous names in science…After two days, I couldn't decide if the atmosphere was more like a children's birthday party or the Mad Hatter's tea party – in either case, everyone was high… the attitude among the string cosmologists seemed to be that anything that wasn't logically disallowed must be out there somewhere. Even things that weren't allowed couldn't be ruled out, because you never knew when the laws of nature might be bent or overruled. This wasn't student fantasizing in some late night beer-fuelled frenzy, it was the leaders of theoretical physics speaking at one of the most prestigious university campuses in the world.*

This illustrates why the claims emanating from this approach should be regarded with considerable caution: they are in many cases unsupported by evidence and based on arbitrary assumptions. Once the gold standard of experimental support has been dropped and basic scientific principles are disregarded,[9] why should such theories be regarded as good science?

7.4 INFINITIES

One particular area where one should be sceptical is as regards the often claimed existence of *physically existing infinities* of universes, and of spatial sections in each universe, in the multiverse context (e.g.Vilenkin 2007). Why should this be so?

- Firstly, if they do indeed occur, they don't occur in a finite time: they are always in the future (Ellis and Stoeger 2009a).
- More fundamentally, one should remember the true nature of infinity: it is an entity that can never be attained, it is always beyond reach. Hence David Hilbert stated: "*the infinite is nowhere to be found in reality, no matter what experiences, observations, and knowledge are appealed t*o" (Hilbert 1964).
- Thirdly, any claim of physically existing infinities is completely untestable: if we could see them, which we can't, we could not count them in a finite time: so we can

[8] Quotation taken from Peter Woit's blog Not even Wrong. Michael Shermer remarks in the Wall Street Journal, "When Ms. Wertheim asked the organizer of the string-theory conference his opinion of one particularly dazzling talk, he enthused: `Utterly splendid. Of course there's not a shred of evidence for anything the fellow said.' "

[9] Example: when I was working on singularity theorems in General Relativity, we regarded a solution as excluded if it implied negative kinetic energies. This is no longer taken to be the case.

never ever prove it true. Hence if science is taken to refer to statements that are at least in principle testable, any such claims are not genuine science.

I nowadays refer to this as *Hilbert's Golden Rule*:

If infinities occur as a core part of your explanatory model, it's not science.

Examples in physics are

- "Boltzmann brain" arguments,[10] which crucially rely on infinities for their startling claims (as well as disregarding the binding energies that are needed for structures to form, and the limits of applicability of quantum theory);
- David Deutsch's arguments in *The beginning of Infinity* (Deutsch 2011) for how the Everett many-worlds version of quantum theory works, where a ratio of uncountably infinite numbers of instances of particles in output channels gives the Born rule;
- The unsolved problems related to probabilities and measure in multiverse models.
- Susskind's use of infinities in arguing the multiverse must have had a beginning (Sussking 2012).

None of these are testable physics.

8 DEEPER ISSUES

In this section, I turn from philosophical issues related to physical cosmology, to a brief encounter with some of the "big questions" that are essentially philosophical.

8.1 THE SCOPE OF ENQUIRY AND LIMITS OF SCIENCE

As stated at the beginning, the first key issue is what you want your model to do. Do you want to describe *how* things came into existence and then developed, or to relate to *why* they came into existence? These are interrelated questions, but the answer to the first cannot imply the answer to the second. Indeed it is crucial that

- ***Scientific models per se cannot answer ultimate why questions***.

Scientific models surely can answer partial why questions such as "why did this star explode in a supernova?", but not ultimate why questions such as "why do the laws of physics exist?" These issues lie outside the scope of the scientific method, which deals with how mechanisms operate. Basically this is because there are no scientific experiments that can answer such "why" questions. Science gains its power of determining unchangeable relentless physical laws and reliably predicting outcomes precisely because it omits such questions from its ambit. That is the ground of its tremendous predictive success.

[10] "Big Brain Theory: Have Cosmologists Lost Theirs?", Dennis Overbye, New York Times, 15 January 2008

But some cosmologists are claiming science can give such answers (Susskind 2006, Hawking and Mlodinow 2010, Krauss 2012). This is a category mistake. It is not true that one can solve the deep questions of existence simply by stating that the laws of physics cause things to be the way they are, and particularly by claiming they bring the universe into existence.[11]

- Firstly this does not explain why the laws are the way they are.
- Secondly this involves extending laws *within* the universe to laws *for* the universe – a huge extrapolation that is definitely untestable. It may not even make sense.
- Thirdly it does not explain in what way these laws existed before the universe came into being – insofar as that idea makes sense.
- The multiverse proposal invoked does not solve any of the fundamental philosophical issues at the foundations of cosmology – all it does is postpone them. Why does the multiverse have the form it does? Where do the supposed laws governing the multiverse come from? And why are they of such a nature as to allow life to exist?

Despite what these authors claim, you can't solve deep philosophical issues by making such assumptions. These arguments are based in a huge untestable philosophical jump from the known to the unknown. What is presented is philosophy, not science – and it is inadequate as philosophy, because it ignores the fundamental issues underlying what it claims to show. The approach is not capable of giving the answers it claims to give. It is ironic to be told that "Philosophy is dead" and then be treated to an exercise in somewhat low level philosophy in the same text.

In the end, despite claiming to present only what science implies, these books present philosophy masquerading as science and speculation masquerading as certainty.

8.2 LIMITS TO MODELS AND THE RELATION TO MATHEMATICS

Underlying the problems with these claims is an inadequacy of the models proposed for investigating the questions that the authors are trying to answer. Theories and models that attempt to answer the deep questions in the philosophy of cosmology must adequately take reality into account. One must remember the limitation of equations as representations of reality, and consider the types of data that will be considered. The cautionary comments are,

- Don't use equations and theories based on limited physical data to try to talk about the metaphysical meaning of the whole,
- Don't stretch equations beyond the limits of their validity.

The strengths and limits of mathematical models are illuminatingly discussed by Eddington in his book *The Nature of the Physical World* (Eddington 1928). He emphasizes how mathematical models are abstractions that omit almost all of reality in favor of a restricted set of variables corresponding to pointer readings. The simplicity of

[11] See the reviews of Krauss' book by David Albert: New York Times, 23 March 2012 and Massimo Pigliucci at http://rationallyspeaking.blogspot.com/2012/04/lawrence-krauss-another-physicist-with.html

this abstraction often enables us to home in on core physical processes at work; but they remain abstractions that omit almost all the details of what is going on. ***One should not confuse these models with reality***. They describe part of reality, not all of it. And each such model has an appropriate domain of application. ***Beware models beyond their domain of validity.***

If you want to use theories or models to discuss philosophical issues, you must use models and data adequate to the task, taking the full complexity of reality into account. Simplistic reductionist models are not adequate to the task.

Example: *The wave function of the universe and the existence of time*:
There is a whole literature[12] claiming that the passage of time is an illusion, even that time does not exist. One of the core arguments is based on the Wheeler de Witt equation for the wave function of the universe, and in essence runs as follows (see e.g. Gibbons, Shellard and Rankin 2003): semi-classical gravity tells us that a wave function of the universe ψ exists and obeys a Schrödinger-like equation:

$$d|\psi>/dt = H|\psi> . \tag{3}$$

But for gravity, the ADM formalism tell us the Hamiltonian vanishes: hence

$$H|\psi> = 0 . \tag{4}$$

Combining (3) and (4) implies

$$d|\psi>/dt = 0: \tag{5}$$

we live in a timeless universe, and so time is an illusion. What appears to be the passage of time is the reading of historical records by the brain (Barbour 1999).

Now this argument involves an extrapolation of quantum physics from atomic to Hubble scales without any comment: it is taken for granted. The linear equation (3) is taken to apply to incredibly non-linear systems like the human brain. This extrapolation is extremely implausible (Ellis 2011a). And the argument rejects all of present day neuroscience, which believes that the operation of the mind is based in the physical brain; if (5) applies to all physical entities it applies to the brain, which therefore (on this argument) can't read anything. But in fact it can (you are reading at present!). One can contrast this simplistic mathematically based argument with the reality of experience (Hoffman 1989):

> *I am walking home from school slowly, playing a game in which it's forbidden to step on the cracks between the slabstone squares of the pavement. The sun is playing its game of lines and shadows. Nothing happens. There is nothing but this moment, in which I am walking toward home, walking in time. But suddenly, time pierces me with its sadness. This moment will not last. With every step I take, a*

[12] Summarised in a special *Scientific American* issue on time: Volume 21, No 1, Spring 2012.

> *sliver of time vanishes. Soon, I'll be home, and then this, this nowness will be the past, I think, and time seems to escape behind me, like an invisible current being sucked into an invisible vortex....*

I suggest the physics that says time does not exist or time does not flow is seriously missing something. We need to adjust the physics theories, not reality. We should do this *inter alia* because the conduct of physics itself depends on this reality: we develop theories, plan experiments, carry them out, analyse them, reach conclusions: none of this would be possible if time did not in fact progressively flow, as we experience it on an everyday basis. Without the passage of time, the scientific enterprise can't happen.

In response to such arguments, Sean Carroll has commented in his blog[13] that the argument is not valid because you must listen to what the equations are saying. Yes indeed, but which are the equations which correctly describe the full complexity of reality? And how do you test that this is the case? There is no experimental evidence the Wheeler de Witt equation holds in any context whatever, and certainly not to the human mind. Just because you have a nice mathematical theory does not prove it is correct! My view (Ellis 2011a) is that the evidence solidly disproves the applicability of the Wheeler de Witt equation to the universe as whole, and to human brains in particular, as proposed by my colleagues. They are not respecting the limits of applicability of this equation – and indeed are ignoring the fact it has not experimentally been shown to apply to any specific physical situation at all. It is another example of hypothetical physics, which has not been shown to hold in the context in which it is being applied. And there are other possibilities: unimodular gravity has a nonvanishing Hamiltonian and hence evolves quantum states in terms of a global time given by an analogue of the Schrödinger equation (Unruh 1989, Unruh and Wald 1989, Sorkin 1994). This may be a better option.

In summary: Models are essential for understanding, ranging from metaphors to detailed maps and full blown mathematical models, but they represent only part of reality, they omit most of what is going on. Don't confuse models with reality! - Particularly when trying to understand the manner of origin of the universe. And if you want your model to relate to existence and the meaning of life then you must take biological processes and complexity seriously, as well as issues to do with the mind, ethics, and meaning. Your models need to adequately include such topics as well the relevant data – related to ethics, aesthetics, and meaning for example. You can't just use highly simplistic physics models and physics data, and on this basis alone talk about issues to do with existence and its relation (or not) to meaning.

If you want to enter this terrain you must take philosophy seriously, and not decry it as meaningless. Eddington states it as follows:

> *Science aims at constructing a world which shall be symbolic of the world of commonplace experience. The external world of physics has thus become a world of shadows. In removing our illusions we have removed the substance, for indeed we have seen that substance is one of the greatest of our illusions. Later perhaps*

[13] http://blogs.discovermagazine.com/cosmicvariance/

> *we may inquire whether in our zeal to cut out all that is unreal we may not have used the knife too ruthlessly. Perhaps, indeed, reality is a child which cannot survive without its nurse illusion. But if so, that is of little concern to the scientist, who has good and sufficient reasons for pursuing his investigations in the world of shadows and is content to leave to the philosopher the determination of its exact status in regard to reality* (Eddington:1928).

8.3 PHYSICAL DETERMINISM AND LIFE TODAY

One of the key issues for cosmology in relation to the big issues is how it relates to daily life. The universe is the overall context for our existence; simplistic use of physics models suggests a form of determinism may reign. The question that arises is,

- ***Is what is happening today on Earth an inevitable outcome of what happened at the start of the universe?***

Many physicists believe this is so; if we had enough computing power, we could predict what is happing today on the basis of complete data in the very early universe.

This view is not correct. The unitary evolution (3) does not apply to the real universe in at least two ways (Ellis 2006a). Firstly, foundational quantum uncertainty means we cannot predict the existence of either the Galaxy or the Earth on the basis of data at the start of inflation. The reason (assuming the standard model of cosmology is correct) is that quantum fluctuations in the inflationary era provided the seeds for large scale structure formation; and they are intrinsically unpredictable (if the standard view of quantum theory is correct). You could not even in principle predict what specific structures would form later from complete data at the start of inflation.

Secondly, we can't predict the existence of the giraffes or humans on the basis of complete data about everything on Earth 2 billion years ago. The reason is that cosmic rays have significantly altered evolutionary history since that time by causing mutations in DNA; and the emission of a cosmic ray is again an intrinsically unpredictable quantum event. On both counts, there is no way that it could be predicted from complete data in the early universe that I would have written what you are now reading, because one could not even have predicted either that the Earth or humans would exist today (I am assuming here that we take basic quantum physics seriously).

So how does it happen that we have come into being, able to take part in complex debates about the evolution and meaning of the universe? The crucial feature is

- ***New kinds of structures with their own causal powers emerge as the universe evolves; they are not uniquely determined by initial conditions.***

The physical models suggesting determinism are faulty both because they do not take quantum uncertainty seriously, and they do not include such possibilities of emergence.

How does this complexity arise? At the astronomical scale, gravity causes structures such as stars and galaxies to come into being spontaneously, locally apparently going against the second law of thermodynamics. This occurs because they are attractors in phase space, so there must be a definition of gravitational entropy that makes it OK. This is still not understood, but is probably related to Weyl tensor, as conjectured by Roger Penrose.At the everyday life scale, to some degree it comes about by self-organisation processes. But they are very limited in what they can achieve. The key process underlying emergence of genuine complexity is *adaptive selection* (Holland 1992, Kaufmann 1993): random processes create an ensemble of initial states from which a preferred final state is chosen according to some selection criteria, the others being discarded. Such selection is the way meaningful information is generated from a jumble of disordered objects: this process selects what is relevant according to the selection criteria and discards all the other incoming information that is not meaningful. Hence biological information can be generated which did not exist before (there was no biological information before galaxies formed: it exists today). There is no way that physics *per se* can predict this outcome.

This process implies both *unpredictability* (the outcome depends on random initial data, hence the role of chance in natural selection) and *irreversibility* (one can't determine the initial state from the final state). Selection can be a once-off process; in biology it gains its power by repetition a huge number of times, but that is not necessary to the concept. It occurs also in physics contexts, for example it underlies state preparation in quantum physics (Ellis 2011). Another example is Maxwell's Demon, where the selection criterion is the speed of molecules approaching a gate between two compartments.
Adaptive selection is an example of top down causation in the hierarchy of complexity, because the outcome depends on the environment that is the context for selection.

8.4 CONTEXT AND TOP DOWN CAUSATION

Complexity is able to come about because the underlying physics enables the existence of modular hierarchical structures, characterized by incredibly complex networks of interactions whose goal-driven mode of operation cannot be encapsulated in statistical physics descriptions.

The Hierarchies of Structure are different on the human science side and the natural science side,[14] but have the same foundations at the lower levels. As characterized by the relevant academic disciplines, they are

Sociology/Economics/Politics	Cosmology
Psychology	Astronomy
Botany/Zoology/Physiology	Space science
Cell biology	Geology
Biochemistry	Materials science
Chemistry	Chemistry
Atomic Physics	Atomic Physics
Particle physics	Particle physics

[14] There is a similar hierarchy for artifacts such as aircraft and computers (Tanenbaum 1990).

As in the case of adaptive selection, often the context is a crucial determinant of outcomes. This is the essence of top-down influence.

Top-down causation and emergence

Physical processes allow the emergence of higher level structures and entities with their own specific natures, which then exert top-down influences on the way the lower level entities operate (Ellis 2008). This enables inter-level feedback loops, which underlie truly complex behaviour. Top down causation is particularly clear in the case of physiology and the human mind, but also occurs for example in microbiology and physics (Ellis, Noble and O'Connor 2012). Causal processes at higher levels proceed according to own higher level logic independent of the specific details of the lower level substratum, and hence are not predictable from the nature or dynamics of that substratum. They in fact control the dynamics of the lower levels -- what happens when and where (piano strings have the same physical behaviour no matter what music is played, and they do not determine the music that is being played; the specific kind of microprocessor in a computer does not determine if it is displaying graphics or playing music).

It is this class of mechanisms that underlies emergence of structure and behaviour not implied by initial conditions in the universe. This in particular enables higher causal levels to emerge with meaning and purpose, for example human minds capable of understanding the nature of cosmology and producing theories such as chaotic inflation.

There is room for such emergence despite the complete description of lower level micro-behavior through standard physical laws; how this can be is discussed in Ellis (2012).

Top down causation in cosmology

Discussion of top-down effects in cosmology has a venerable history, and relates to the discussion in Section 5.2. Particular cases are

1. ***Mach's Principle***: what is the origin of inertia?,
2. ***Olber's paradox***: why is the sky dark at night?,
3. ***The determination of the arrow of time***: how does a direction of time emerge from underlying physics that is time symmetric?

These are discussed in Ellis and Sciama (1972), Harrison (2000), Ellis (2002, 2006). The arrow of time issue is the most pressing of them in terms of current physical thought (Penrose 2011, Carroll 2010, Ellis 2011b), but it is Mach's Principle that has had the most influence on the development of theoretical physics through Einstein's development of General Relativity as well as his static universe model. Both were heavily influenced by his musings on Mach's Principle.A subtle further example is that non-interference is a particular case of top-down relations of the universe to local systems. There are many ways the cosmos could interfere with local events, for example through high intensity cosmic rays or gravitational waves, and hence prevent the possibility of local deterministic physical outcomes. But this does not occur, hence local isolated systems can exist (Ellis 2008):

4. ***The existence of isolated systems in the expanding universe***: why does the universe not interfere with local physics?

This depends on the cosmological context, which enables local systems to evolve independent of distant regions, see Ellis and Stoeger (2009) for a discussion.

Items 2.-4. are necessary for the existence of life, and so relate to the Anthropic issue (Section 6.1). One of the most interesting issues in the future development of cosmology may well lie in further development of understanding of the interaction between bottom-up and top-down effects in the physical universe.

8.5 POSSIBILITY SPACES AND THE NATURE OF CAUSATION

One of the most remarkable features of the cosmos is the emergence of totally new kinds of existence as events take their course: stars, planets, living cells, human minds come into being that were not there before. The fundamental issue is,

- ***To what extent is this development inevitable? Was it necessary that it occurred?***

This depends on deep issues as to the nature and existence of causation.

Four different types of causation occur in the universe:

1. ***Random events*** meaninglessly making things happen [chance],
2. ***Purposeless algorithms*** grinding away [necessity],
3. ***Selection processes*** creating order where there was none [adaptation],
4. ***Purposeful action*** related to understanding, meaning, ethics, aesthetics [purpose].

The first two are those recognized by Monod (1972), but the third and fourth demonstrably happen in the real universe; they somehow (in ways not yet understood) eventually come into existence as a result of the first two, with the third underlying the fourth.

Now the latter three each have a possibility space characterizing the nature of what may come into being (Ellis 2004), in a sense equivalent to the essential dynamics of that kind of causation. The deep question is

- ***Why does the possibility space for each exist and have the form it does***?

These are the deep foundations for what is possible, and hence for what exists.

The possibility space for 2. is essentially equivalent to the laws of physics, see Section 7.1, perhaps incorporating the `landscape' envisaged by M theory but also for example the solution spaces for differential equations characterized by dynamical systems theory (Wainwright and Ellis 1996). The possibility space for 3. entails the fitness landscape of evolutionary theory in biology. The possibility space for 4. is the space of all possible thoughts, which (in accordance with section 7.4) is finite because the set of meaningful sentences if finite, see Ellis and Stoeger (2008). Now each of these possibility spaces underlies what can happen in the physical universe, and are unchanging and eternal, like mathematics and the laws of physics. Indeed they arguably all pre-exist the universe (at least that is what is implied for example by the arguments of Hawking and Mlodinow, even though they only refer to the second one). The nature of possibilities does not change as the universe evolves: what changes is which of them is realised in actuality.

The fourth category entails the possibilities for ethics, thoughts, aesthetics, and meaning. The really deep question is where does this come from:

- ***Can meaning really emerge out of non-meaning***?

This is highly implausible.[15] The various aspects of meaning have their own logic embodied in their possibility space, which cannot plausibly arise in any way out of physics: their nature and logic is completely different. Endeavours such as evolutionary psychology claim to explain for example where morality comes from on evolutionary principles; but this project (which has many problematic aspects)[16] presumes the existence of this possibility space. In some sense, like mathematics and the laws of physics, it lies at the foundations of the complex existence we experience: for without this being the case, these aspects of life could not come into being. These possibilities are in some sense pre-ordained in the nature of the cosmos.

One may or may not agree with this line of argument, but the point to make is two-fold: if one wants to relate cosmology to meaning then this is the kind of territory one has to get into; and secondly to explore it one needs to consider data that relates to the whole of life, including ordinary human experience - not just the data from physics and astronomy. And one cannot encompass these arguments in equations; they take you part of the way, but in the end omit the essence of what is at stake.

If you want your model to relate to the existence and meaning of life then you must take biological processes and complexity and daily life seriously - as well as physics and astronomy. You can't just use highly simplistic physics models and talk about the origin of self consciousness, or make sensible statements about the origin of meaning – which certainly exists; if this were not so, you would not be reading this paper.

8.6 ULTIMATE CAUSATION AND EXISTENCE

The issue of ultimate causation asks,

- Why does anything exist?
- Which of the four kinds of causation just mentioned (Section 8.5) is fundamental and which derivative?

This obviously relates to the existence of intelligent life and the anthropic issue (`Why does human life exist?').

The argument above has been that possibility of mind, and its capacity to relate to meaning, is built into the foundations of existence: we could not exist as we do if this were not true. The ultimate question (Ellis 2011) is whether that is just a most incredible fluke, or if it requires explanation just as much as the purely physical stuff going on. And

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[15] My primary school motto was "Ex nihlo nihil fit" – out of nothing, nothing can be made.

[16] The evolutionary psychology approach does not take biology seriously, and has difficulty relating to the deep nature of ethics. Various arguments support rather the idea of ethical realism.

proposing a multiverse does not help: the issue arises just as much for whatever underlies existence of the multiverse as it does for a single universe.

Usually science continues to search for explanations for any conundrum it encounters; but in this case a solution cannot be found through physics alone, for physics simply does not comprehend the concept of mind. Other kinds of causation are at work than just physical. I will not pursue this further here except to reiterate that you must use models and data of adequate scope for your enquiry if you enter this terrain, and you must then take philosophy seriously, rather than decrying it as meaningless.

Actually we know there is more than physical causation at work in the universe: purpose does exist and is causally effective (we each experience it every day in our ordinary daily life). Physical analysis alone cannot tell us why.

9 REPRISE

Is the philosophy of cosmology necessary? Is it worthwhile?

I suggest it is useful in relation to issues in physical cosmology, helping to clarify the nature of what is being done and how different approaches fit together; and that it is essential if one wants to look at the bigger picture. In my view, we benefit by now and then stepping back and considering the big picture: thinking about what are we doing and what methods we are using to do it. Such meta-analysis is valuable – or else technical analysis may go off in the wrong direction, claiming more than it can in fact achieve, and key issues may be missed. Such an analysis must be willing to look at all our experience and all the data facing us, not just that determined by physics and astronomy. We are part of the universe, and our life experiences are evidence as to its nature. This is an instance of the deep relation between cosmos and man which has been on the agenda in cosmology from Pythagoras and Plato onwards.

* * *

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REFERENCES

A Avgoustidis, G Luzzi, C J A P Martins, and A M RV L Monteiro (2011) “Constraints on the CMB temperature-redshift dependence from SZ and distance measurements” [arXiv:1112.1862v1 astro-ph.CO].

J B Barbour (1999) *The End of Time: The Next Revolution in Physics* (Oxford: Oxford University Press).

J Barrow and F Tipler (1986). *The Anthropic Cosmological Principle*. Oxford University Press.

J D Bekenstein (2012) “Tensor-vector-scalar-modified gravity: from small scale to cosmology” [arXiv:1201.2759v1].

J.R. Bond, C.R. Contaldi, A.M. Lewis, and D. Pogosyan (2004) “The Cosmic Microwave Background and Inflation Parameters” *Int.J.Theor.Phys*. **43**: 599-622 [arXiv:astro-ph/0505581]

H Bondi (1960) *Cosmology* (Cambridge: Cambridge University Press).

W B Bonnor and G F R Ellis (1986) ``Observational homogeneity of the universe". *Mon Not Roy Ast Soc* **218,** 605-614.

R H Brandenberger (2009) “Alternatives to Cosmological Inflation”, *Physics Today* **61**, No 3 [arXiv:0902.4731v1].

J Butterfield (2012) “Under determination in cosmology”. Presidential address to the Mind Society.

B J Carr (Ed) (2009) *Universe or Multiverse*? (Cambridge: Cambridge University Press).

S Carroll (2010) *From Eternity to here: the quest for the ultimate arrow of time* (New York: Dutton).

J-P Changeux and A Connes (1998) *Conversations on Mind, Matter, and Mathematics* **(**Princeton University Press)

C Clarkson, B A Bassett, and T H-C Lu (2007) “SN observations A general test of the Copernican Principle” *PhysRevLett*.**101**: 011301 [arXiv:0712.3457v2].

C Clarkson and R Maartens (2010) “Inhomogeneity and the foundations of concordance cosmology” *Class. Quantum Grav.* **27** 124008 [arXiv:1005.2165].

T Clifton, C Clarkson, and P Bull (2012) “CBR observations The isotropic blackbody CMB as evidence for a homogeneous universe” [arXiv:1011.4920v1 [gr-qc]].

N J Cornish, DN. Spergel, and G D Starkman G D. (1998.) ``Circles in the Sky: Finding Topology with the Microwave Background Radiation’’ *Class.Quant.Grav*. **15** : 2657-2670 [arXiv:gr-qc/9602039].

D Deutsch (2011) *The beginning of Infinity: Explanations that transform the world* (Viking Adukt).

S Dodelson (2003) *Modern Cosmology* (New York: Academic Press).

A S Eddington (1928). *The Nature of the Physical World*. (London: MacMillan).

G F R Ellis (1971): ``Relativistic Cosmology''. In *General Relativity and Cosmology, Proc Int School of Physics ``Enrico Fermi''*, Course XLVII. Ed. R K Sachs (Academic Press), 104-179. Reprinted as Golden Oldie: *Gen. Rel. Grav.* **41**, no 3, 581 (2009) **.**

G F R Ellis (1971a): ``Topology and Cosmology''. *Gen Rel Grav* **2**, 7-21.

G F R Ellis (2002) ``Cosmology and Local Physics''. *New Astronomy Reviews* **46**: 645-658 [http://arxiv.org/abs/gr-qc/0102017].

G F R Ellis (2004) "True Complexity and its Associated Ontology''. In *Science and Ultimate Reality: Quantum Theory, Cosmology and Complexity, honoring John Wheeler's 90th birthday*. Edited by John D. Barrow, Paul C.W. Davies, and Charles L. Harper, Jr. (Cambridge University Press).

G F R Ellis (2006) ``Issue in the Philosophy of cosmology'' In *Handbook in Philosophy of Physics*, Ed J Butterfield and J Earman (Elsevier, 2006), 1183-1285 [http://arxiv.org/abs/astro-ph/0602280].

G F R Ellis (2006a) " Physics in the Real Universe: Time and Spacetime". *GRG* **38**:1797-1824 [http://arxiv.org/abs/gr-qc/0605049].

G F R Ellis (2008) ``On the nature of causation in complex systems'' *Trans Roy Soc South Africa* **63**: 69-84 [http://www.mth.uct.ac.za/~ellis/Top-down%20Ellis.pdf.]

G F R Ellis (2011), "Why Are the Laws of Nature as They Are? What Underlies Their Existence?" In *The Astronomy Revolution: 400 Years of Exploring the Cosmos*, ed D York, O Gingerich, and S-N Zhang (Francis and Tayler), 385-404.

G F R Ellis (2011a) "On the limits of quantum theory: Contextuality and the quantum-classical cut" [http://lanl.arxiv.org/abs/1108.5261].

G F R Ellis (2011b) "The arrow of time, the nature of spacetime, and quantum measurement" http://www.mth.uct.ac.za/~ellis/Quantum_arrowoftime_gfre.pdf.

G F R Ellis (2012) "Top down causation and emergence: some comments on mechanisms" *Journ Roy Soc Interface Focus* **2**: 126-140.

G F R Ellis and J Baldwin (1984) ``On the expected anisotropy of radio source counts''. *Mon Not Roy Ast Soc* **206**, 377-381.

G F R Ellis, R Maartens and M A H MacCallum (2012) *Relativistic Cosmology* (Cambridge: Cambridge University Press).

G F R Ellis, D Noble, and T O'Connor (Eds) (2012) "Top down causation: an integrating theme across the sciences?" *Royal Society Interface Focus* **2** (Special Issue).

G F R Ellis and T Rothman (1993): “Lost Horizons”. *Am J Phys* **61**: 93.

G F R Ellis and G Schreiber (1986) ``Observational and dynamic properties of small universes". *Phys Lett* **A115**: 97-107.

G F R Ellis and D W Sciama (1972) ``Global and non-global problems in cosmology". In *General Relativity (A Synge Festschrift)*, ed. L. O'Raifeartaigh (Oxford: Oxford University Press), 35-59.

G F R Ellis and W R Stoeger (2008) “Language infinities”, available at http://www.mth.uct.ac.za/~ellis/Language%20infinities.pdf.

G F R Ellis and W R Stoeger (2009) ``The Evolution of Our Local Cosmic Domain: Effective Causal Limits" *Mon Not Roy Ast Soc* **398**:1527-1536 [http://arxiv.org/abs/1001.4572].

G F R Ellis and W R Stoeger (2009a), “A Note on Infinities in Eternal Inflation”. *Gen.Rel.Grav*.**41**:1475-1484 [arXiv:1001.4590v1**].**

G F R Ellis and J-P Uzan (2005): “`c' is the speed of light, isn't it?” *Am.J.Phys*. **73**: 240-247 [arXiv:gr-qc/0305099v2].

G F R Ellis, H van Elst, J Murugan, and J-P Uzan (2011) “On the Trace-Free Einstein Equations as a Viable Alternative to General Relativity” *Class.Quant.Grav*. B: 225007 [**arXiv:1008.1196**]

B Freivogel, M Kleban, M R Martinez, and L Susskind (2006) ``Observational Consequences of a Landscape’’: *JHEP* 0603:039 [arXiv:hep-th/0505232].

G W Gibbons, E P S Shellard and S J Rankin (Eds) (2003) *The Future of Theoretical physics and Cosmology: Celebrating Stephen Hawking's 60th Birthday* (Cambridge: Cambridge University Press).

E R Harrison (2000) *Cosmology: The Science of the Universe* (Cambridge: Cambridge University Press).

S W Hawking and L Mlodinow (2010) *The Grand Design* (Bantam).

D Hilbert (1964). “On the Infinite”. In *Philosophy of Mathematics*, Ed. P Benacerraf and H Putnam (Englewood Cliff, N. J.: Prentice Hall), 134.

C Hoefer (2010) "Causal Determinism", *The Stanford Encyclopedia of Philosophy (Spring 2010 Edition)*, Edward N. Zalta (ed.), at http://plato.stanford.edu/archives/spr2010/entries/determinism-causal/

Eva Hoffman (1994): *Lost in Translation: A Life in a New Language* (Penguin).

R. F. L. Holanda, R. S. Goncalves, and J. S. Alcaniz (2012) "A test for cosmic distance duality" [arXiv:1201.2378 astro-ph.CO] .

J H Holland (1992) *Adaptation in natural and artificial systems* (Cambridge, Mass: MIT Press).

C Howlett, A Lewis, A Hall, and A Challinor (2012) "CMB power spectrum parameter degeneracies in the era of precision cosmology" . ArXiv:1201.3654

S A Kauffman (1993) *The Origins of Order: Self-Organisation and Selection in Evolution* (New York: Oxford).

S Khedekar and S Chakrabort (2011) "A new Tolman test of a cosmic distance duality relation at 21 cm" [arXiv:1105.1138].

L Krauss (2012) *A Universe from Nothing: Why There Is Something Rather Than Nothing* (Free Press, 2012)

M Lachieze-Ray and J P Luminet (1995). "Cosmic Topology" *Phys. Rep*. **254**, 135.

I Lakatos (1978). *The Methodology of Scientific Research Programmes: Philosophical Papers Volume 1*. Cambridge: Cambridge University Press

A D Linde (2003). "Inflation, Quantum Cosmology and the Anthropic Principle". In *Science and Ultimate Reality: From Quantum to Cosmos*, ed J D Barrow et al (Cambridge: Cambridge University

Y-Z Ma, W Zhao, and M L Brown (2010) "Constraints on standard and non-standard early Universe models from CMB B-mode polarization" *JCAP* **1010**:007,2010 [arXiv:1007.2396].

W H McCrea (1953), "Cosmology". *Rep Prog Phys* **16**: 321.

D M Meyer (1994), "A distant space thermometer". *Nature*: **371**, 13

J Monod (1972) *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology* (Vintage Books)

M K Munitz (1962), "The logic of cosmology". *British J Philos Sci*, **13**:104.

N Mustapha, C Hellaby and G F R Ellis (1999) "Large Scale Inhomogeneity vs Source Evolution: Can we Distinguish Them?" *Mon Not Roy Ast Soc* **292**: 817-830.

K A Olive, M Peloso, and J-P Uzan (2011) "The Wall of Fundamental Constants" *Phys.Rev.***D83**: 043509 [arXiv:1011.1504].

Penrose, R (1997). *The Large, the Small, and the Human Mind* (Cambridge: Cambridge University Press).

R Penrose (2011) *Cycles of Time: An Extraordinary New View of the Universe* (New York: Knopf).

M J Rees (1999) *Just Six Numbers: The Deep Forces that Shape the Universe* (London: Weidenfeld and Nicholson).

M J Rees (2001) *Our Cosmic habitat* (Princeton: Princeton University Press).

M Regis and C Clarkson (2010) "Do primordial Lithium abundances imply there's no Dark Energy?": arXiv:1003.1043.

S E Rugh and H Zinkernagel (2009) "On the physical basis of cosmic time" *Stud.Hist.Philos.Mod.Phys*. **40**:1-19 [arXiv:0805.1947v1]

S E Rugh and H Zinkernagel (2011) "Weyl's principle, cosmic time and quantum fundamentalism": in D. Dieks et al. (eds.), *Explanation, Prediction, and Confirmation*. (Springer), pp:. 411-424 [arXiv:1006.5848v1]

J Silk (2001) *The Big Bang* (New York: Freeman).

R.D. Sorkin (1994) `On the Role of Time in the Sum-over-histories Framework for Gravity" *Int. J. Theor. Phys*. **33**:523-534.

D N Spergel, R Bean, O Doré, M R Nolta, C L Bennett, J Dunkley G Hinshaw, N Jarosik, E Komatsu, L Page, H V Peiris L Verde, M Halpern, R S Hill, A Kogut, M Limon, S S Meyer, N Odegard, G S Tucker, J L Weiland, E Wollack, E L Wright (2007) "Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Results: Implications for Cosmology" *Astrophys.J.Suppl*.170:377 [arXiv:astro-ph/0603449].

G D Starkman (2012) "Modifying Gravity: You Can't Always Get What You Want" [arXiv: 1201.1697v1].

G D Starkman, C J Copi, D Huterer, and D Schwarz (2012) "The Oddly Quiet Universe: How the CMB challenges cosmology's standard model": arXiv:1201.2459.

W Stoeger, R Maartens and G F R Ellis (1995): "Proving almost-homogeneity of the universe: an almost-Ehlers, Geren and Sachs theorem". *Ap J* **443**: 1-5.

D Sudarsky (2011) "Shortcomings in the Understanding of Why Cosmological Perturbations Look Classical" *Int.J.Mod.Phys*.**D20**:509-552 [arXiv:0906.0315v3]

L Susskind (2006) *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*. Back Bay Books

L Susskind (2012) "Was There a Beginning?" [http://lanl.arxiv.org/abs/1204.5385].

A S Tanenbaum, (1990) *Structured Computer Organisation* (Englewood Cliffs: Prentice Hall).

M Tegmark (2004). "Parallel Universes" In *Science and Ultimate Reality: From Quantum to Cosmos*, ed J D Barrow et al (Cambridge: Cambridge University Press) [astro-ph/0302131].

M Tegmark, M Zaldarriaga, and A J S Hamilton (2001) "Towards a refined cosmic concordance model: joint 11-parameter constraints from CMB and large-scale structure" *Phys.Rev*.**D63**:043007 [arXiv:astro-ph/0008167].

W G Unruh (1989) "A Unimodular Theory Of Canonical Quantum Gravity", *Phys.Rev*.**D40**: 1048.

W G Unruh and RM Wald (1989) "Time And The Interpretation Of Canonical Quantum Gravity". *Phys.Rev*.**D40**:2598.

J-P Uzan (2010) "Varying constants, Gravitation and Cosmology" *Living Reviews in Relativity* [arXiv:1009.5514].

A Vilenkin (1982) "Creation of Universes From Nothing". *Phys.Lett.* **B117**, 25.

A Vilenkin (2007) *Many Worlds in One: The Search for Other Universes* (Hill and Wang).

J Wainwright and G F R Ellis (Ed) (1996) *Dynamical systems in cosmology* (Cambridge: Cambridge University Press).

D H Weinberg, M J Mortonson, D J Eisenstein, C Hirata, A Riess, and E Rozo (2012) "Observational Probes of Cosmic Acceleration": arXiv:1201.434v1.

S Weinberg (1989) "The Cosmological constant problem". *Rev. Mod. Phys.* 61, 1-23

S Weinberg (2000) “The Cosmological Constant Problems”: astro-ph/0005265.

M Wertheim (2012): *Physics on the Fringe: Smoke Rings, Circlons and Alternative Theories of Everything* (Walker & Company).

H Zinkernagel (2011) ``Some Trends in the Philosophy of Physics’’"Theoria, 71; pp. 215-241.

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Version: 2012-05-01
Email: george.ellis@uct.ac.za

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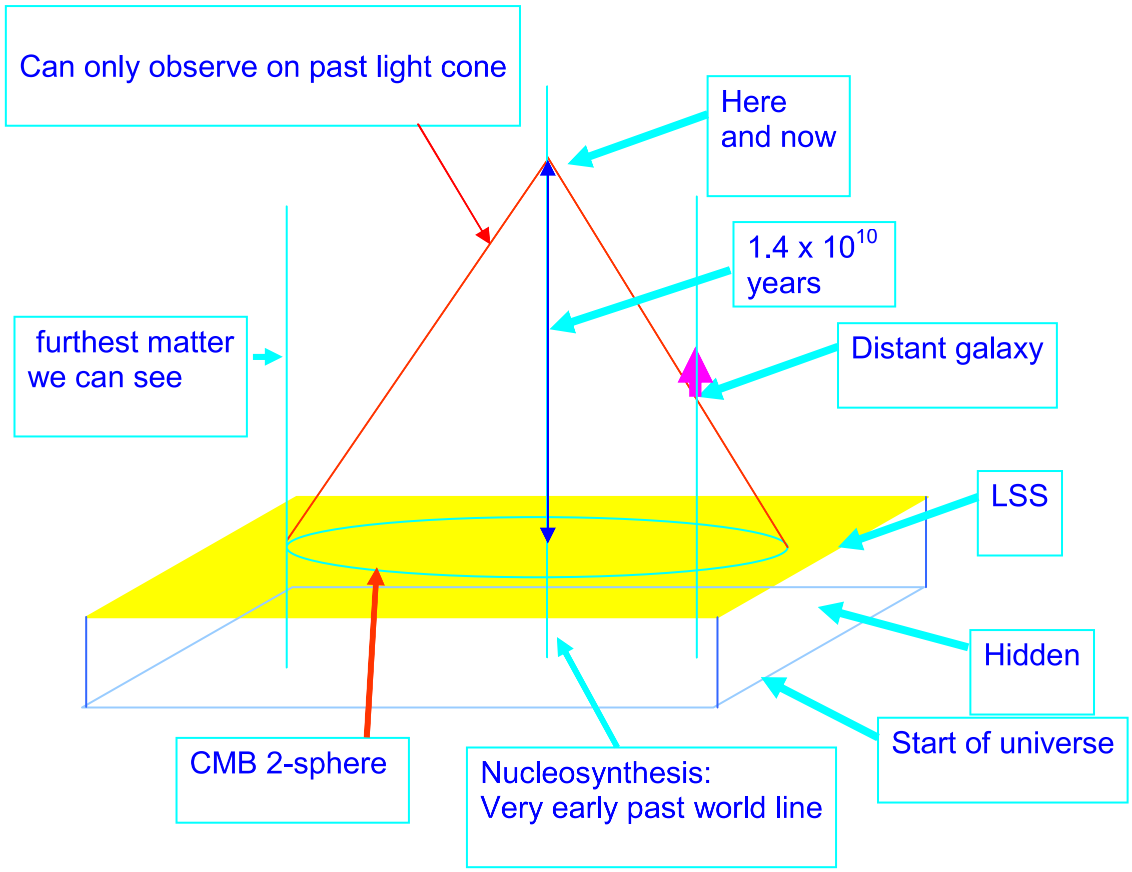

Figure 1: The basic observational situation in cosmology.
Conformal coordinates are used so that fundamental world lines are vertical lines, surfaces of homogeneity are horizontal planes, and null cones are at $\pm45^{o}$. Spatial distances are distorted but causal relations are as in flat spacetime. The start of the universe is at the bottom. The universe was opaque until the Last Scattering Surface (LSS), where radiation decoupled from matter, and propagated freely from then on as cosmic black body radiation, nowadays peaked in the microwave region at 2.75K. Our world line is at the centre of the diagram; the present event "here and now" is about 14 billion years after decoupling. We see a distant galaxy at the instant it crosses our past light cone. All events before the LSS are hidden from our view; as the LSS is where the freely propagating cosmic microwave background (CMB) originates, it is the CMB 2-sphere we see when we measure temperature fluctuations in the CMB across the sky (Figure 2). Nucleosynthesis took place shortly after the start of the universe and determined the primordial abundance of light elements.

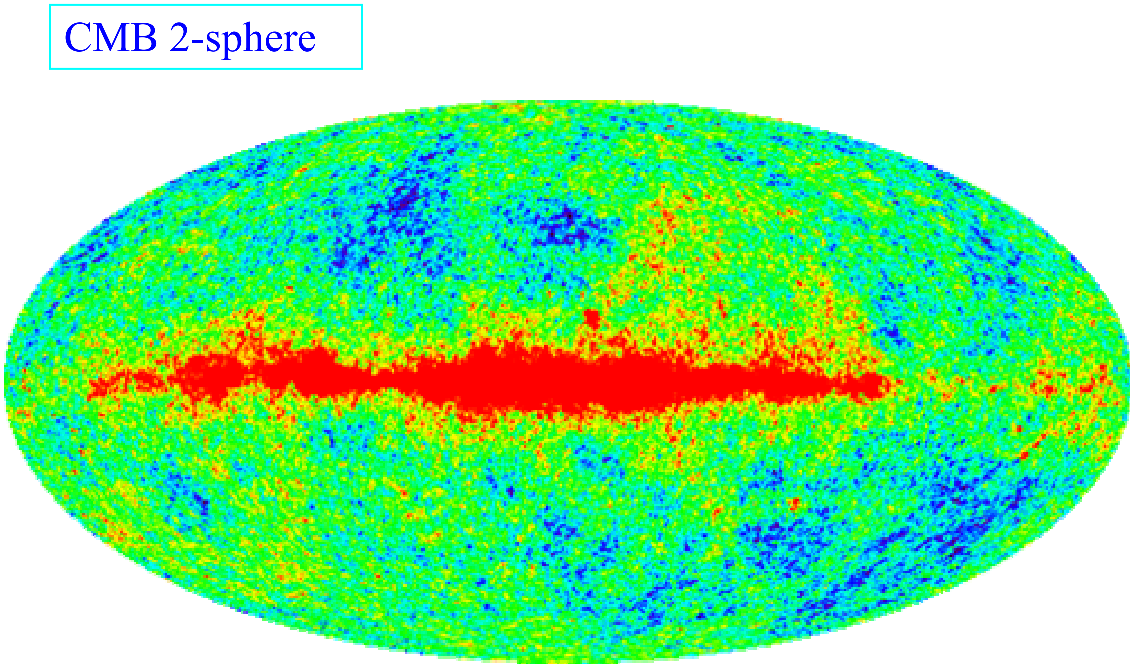

Figure 2: **The CMB 2-sphere**
Microwave background radiation anisotropy over the entire sky is depicted, with the dipole due to our motion removed. This images the Last Scattering Surface (LSS), with our galaxy superimposed in the foreground. Anisotropy is present at one part in 100,000, representing primordial fluctuations that are the seeds for large scale structure formation at much later times. The matter emitting this radiation is the most distant matter we can see in the universe: their world lines constitute our visual horizon. This 2-sphere is the intersection of our past light cone with the LSS: we cannot see the matter on the LSS to the interior of this 2-sphere (see Figure 1).

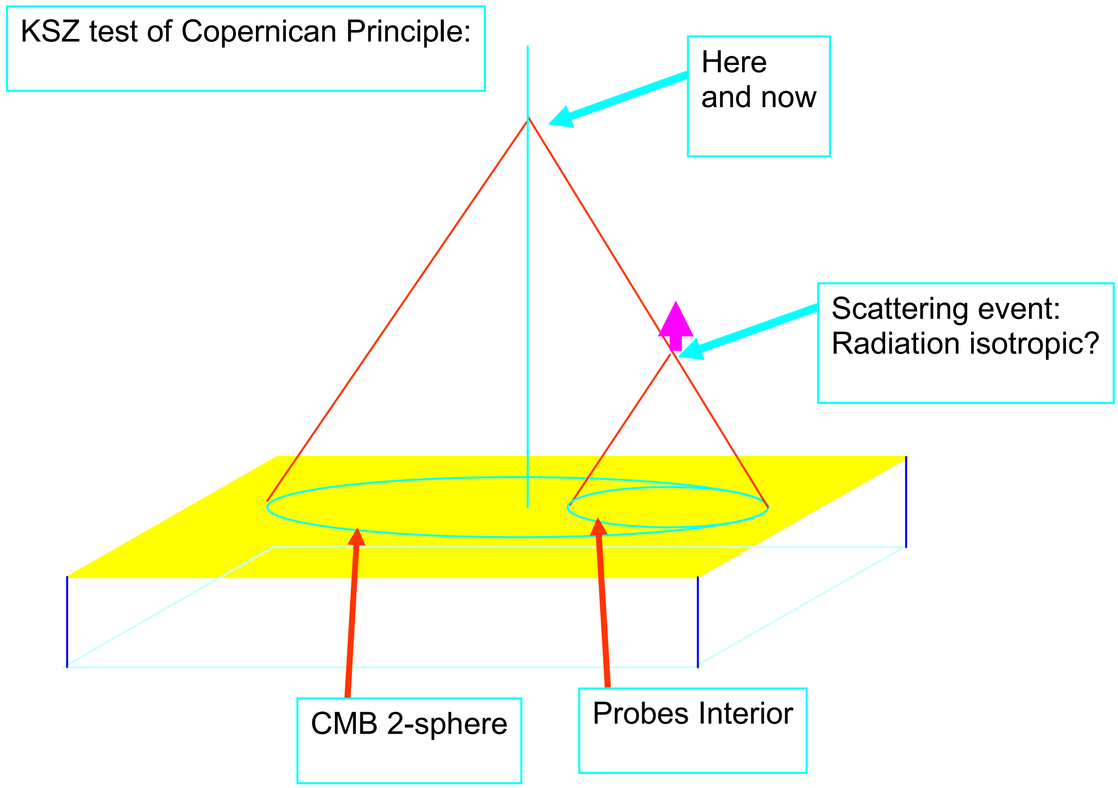

Figure 3: KSZ test of Copernican principle. We can see if the CMB is isotropic out there, at a distance down our past light cone: then the almost EGS theorem applies and confirms we live in an almost-FLRW universe. This test probes the interior of the CMB 2-sphere on the LSS.

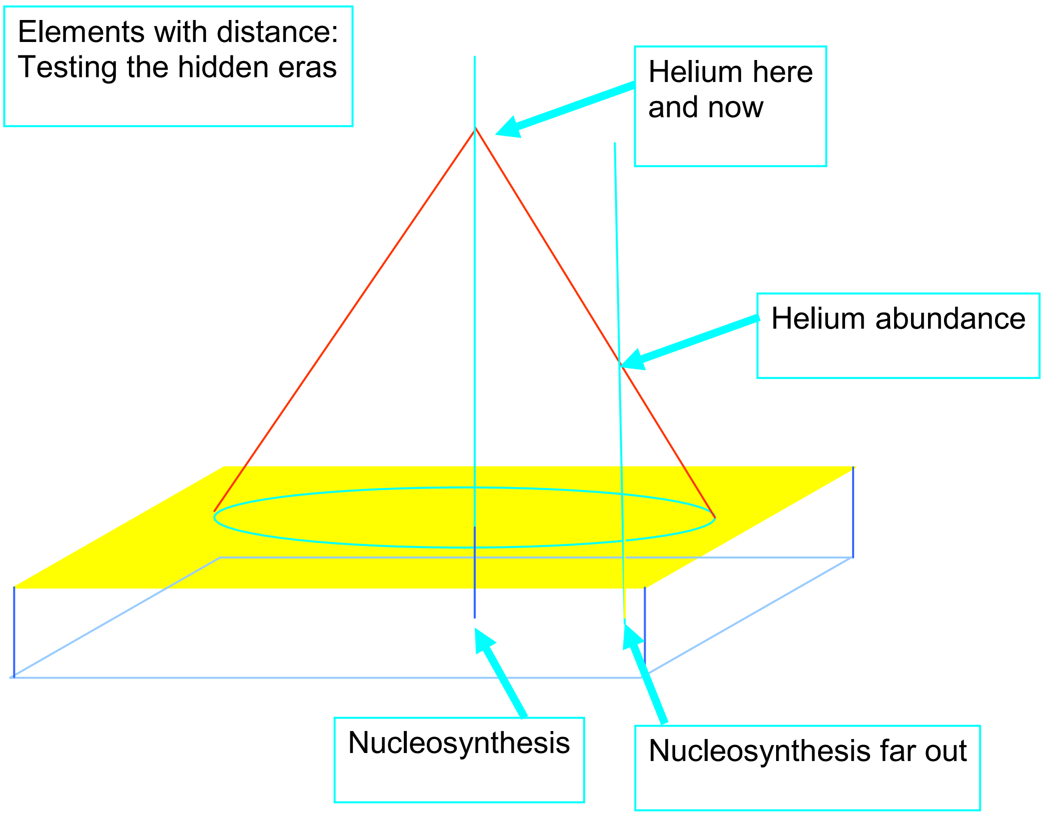

Figure 4: **Distant element abundances**
Testing element abundances at high redshift enables us to investigate conditions at very early times (long before the LSS) at large distances from our world line. Nucleosynthesis occurs during the first three minutes of the history of the Hot Big Bang, and is sensitive to the expansion rate at that time; which is determined by the geometry and matter content then.

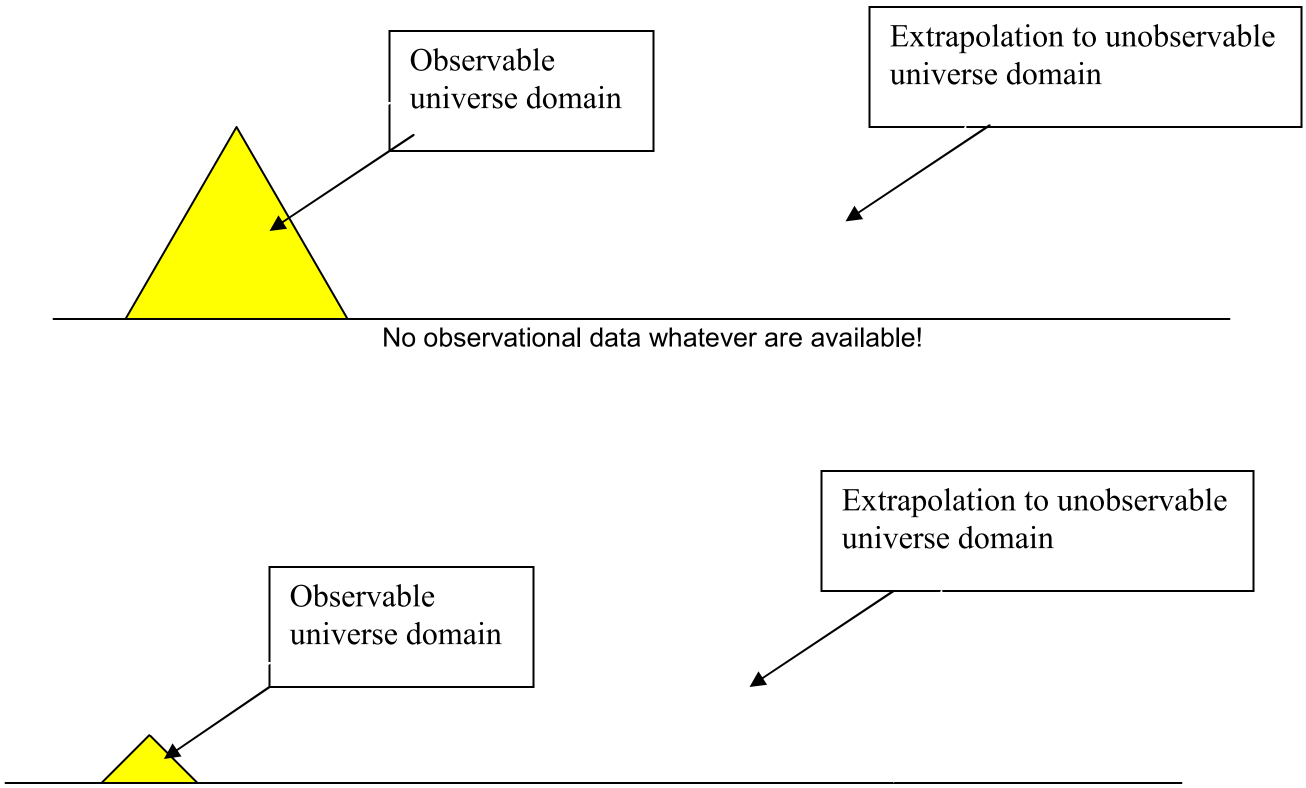

Figure 5: **Observational limits outside our past null cone, at two different scales**. No observational data are available however anywhere beyond the shaded triangles, no matter what observational techniques are used. The assumption made in multiverse theories is that we can extrapolate from the observable domain to determine the nature of the situation at 100 Hubble radii, 10^{1000} Hubble radii, or much, much more distant from us (the word `infinity' is often used). This is extrapolation on a truly grand scale. We cannot remotely test if it is true or not. Statements about what is out there are faith-based statements rather than empirically testable proposals.