Multiverses: a scientific proposal ?

George Ellis

Talk at Oxford Meeting
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:

"Multiverses and Cosmology: Philosophical Issues"
W. R. Stoeger, G. F. R. Ellis, U. Kirchner
http://xxx.arXiv.org/abs/astro-ph/0407329

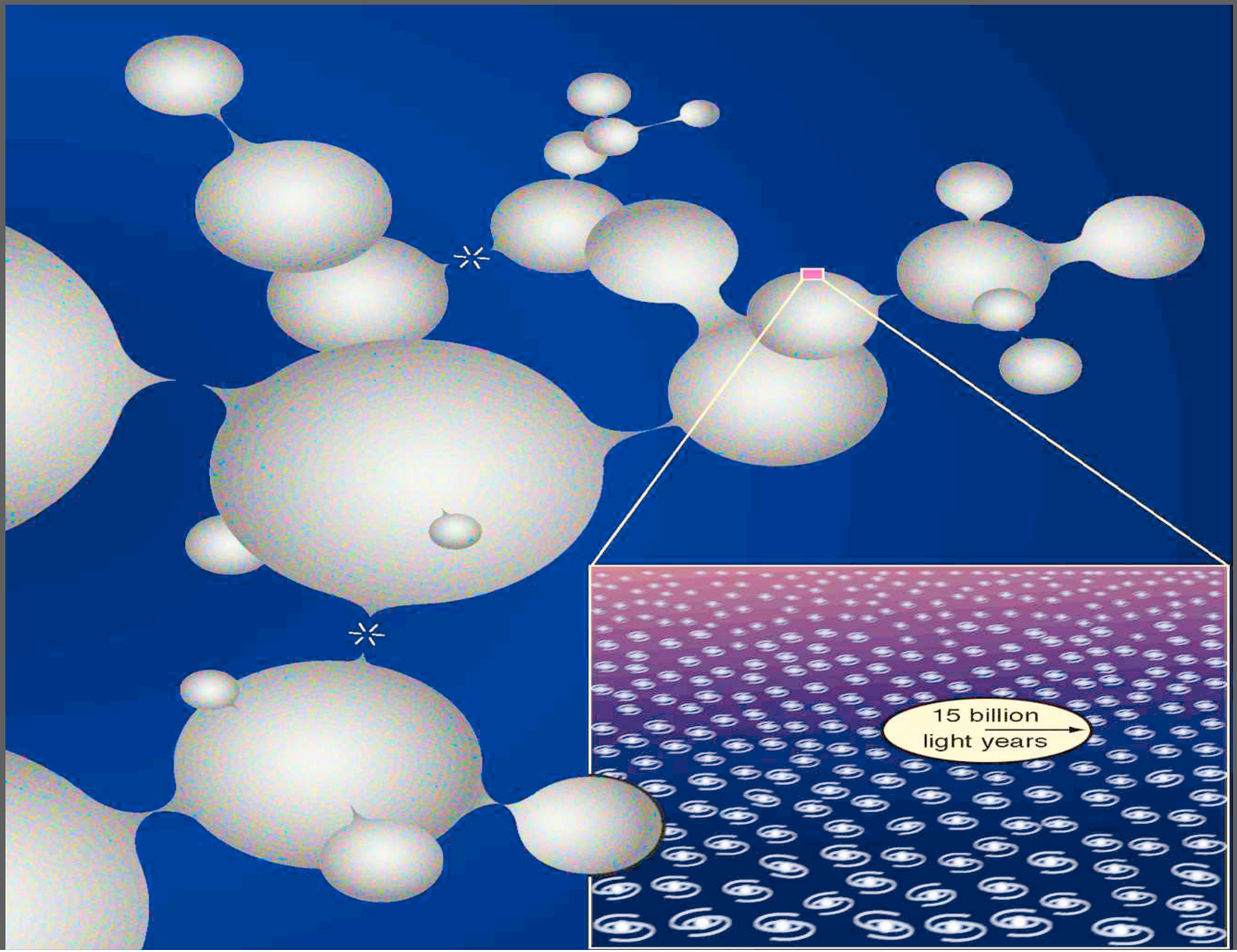
The idea

The idea of a multiverse -- an ensemble of universes or of universe domains – has received increasing attention in cosmology

- separate places [Vilenkin, Linde, Guth]
- separate times [Smolin, Penrose, cyclic universes]

- the Everett quantum multi-universe: other branches of the wavefunction [Deutsch]
- the cosmic landscape of string theory, imbedded in a chaotic cosmology [Susskind]

- totally disjoint [Sciama, Tegmark, Rees]


15 billion
light years

Fine tuning: The Anthropic Issue [Brandon Carter]

• **"The universe is fine-tuned for life" [J Barrow and F Tipler, *The Anthropic Cosmological Principle;* Fred Hoyle]**

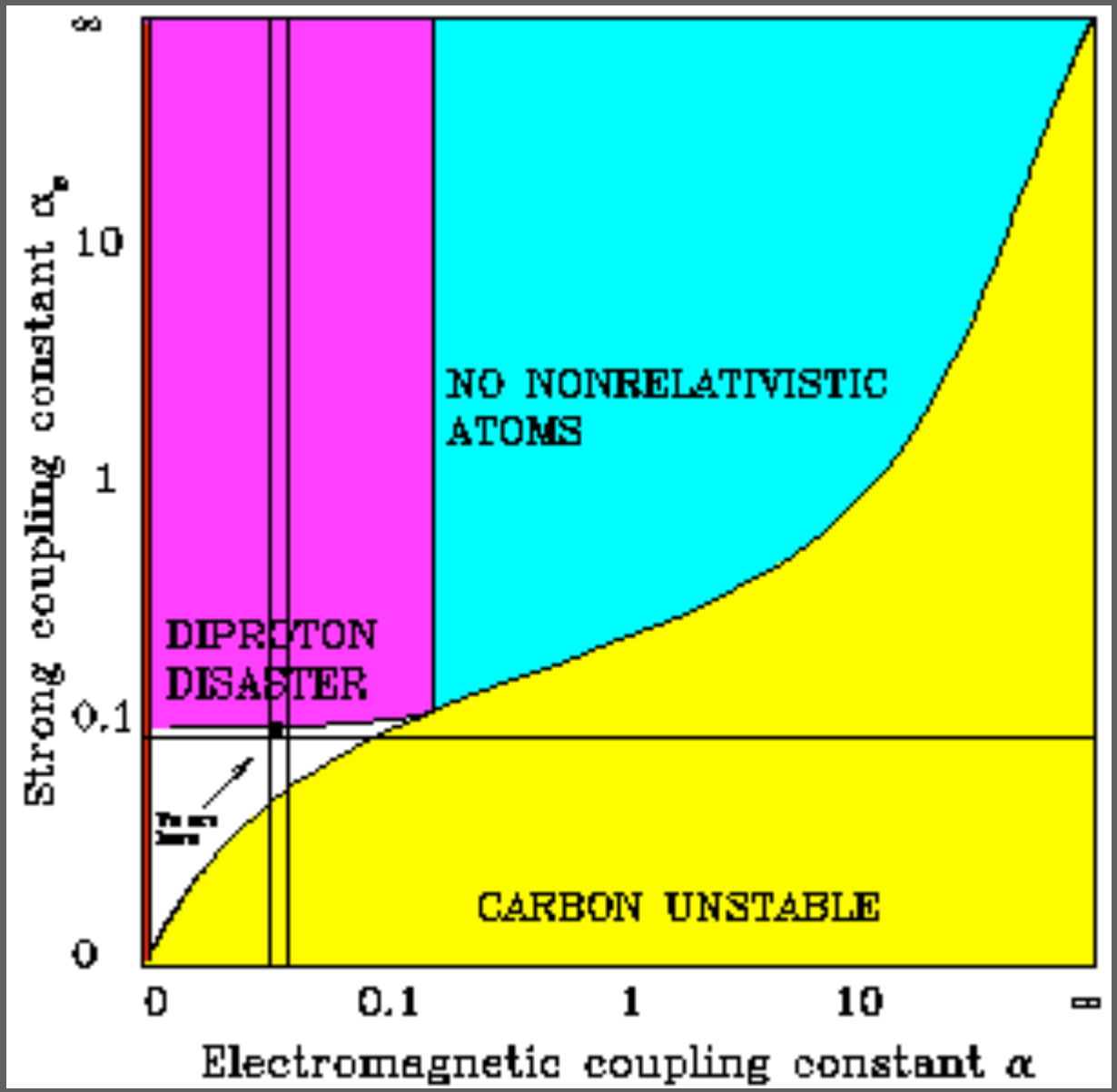
- as regards the laws of physics [Carr and Rees, Max Tegmark: "Parallel Universes" astro-ph/0302131]

- as regards the boundary conditions of the universe [Martin Rees: *Just Six Numbers*, *Our Cosmic habitat*]

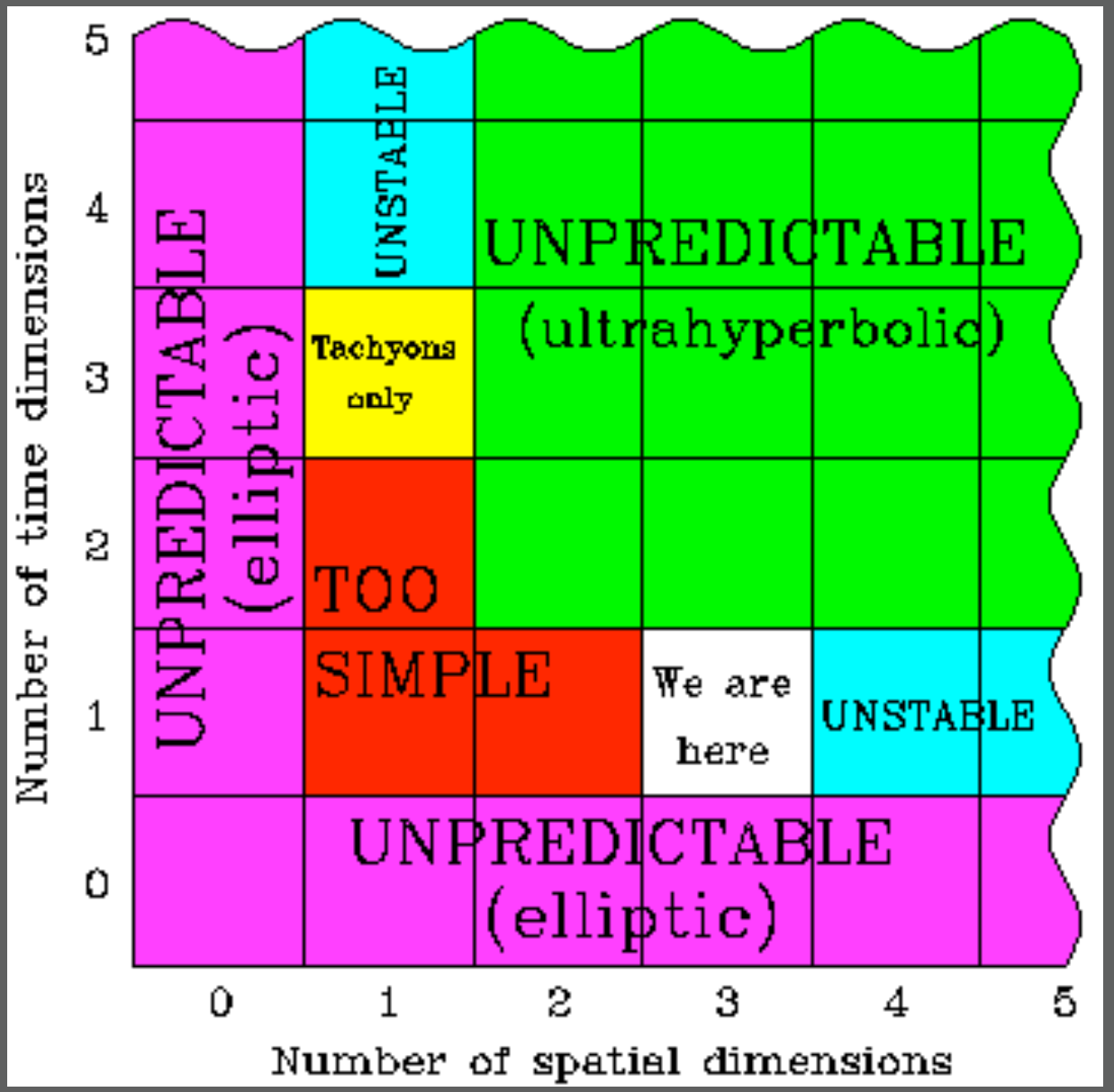
• **A multiverse with varied local physical properties is one possible scientific explanation:**

-an infinite set of universe domains allows all possibilities to occur, so somewhere things work out OK

• **NB: it must be an *actually existing* multiverse - this is essential for any such anthropic argument**



Limits on physics allowing complex structures [Max Tegmark]



Only special dimensions allow complex systems [M Tegmark]

Application: *explaining fundamental constants*

Particularly: explaining the small value of the cosmological constant [Steven Weinberg: astro-ph/0005265; Susskind, *The Cosmic Lansdscape*] by anthropic argument

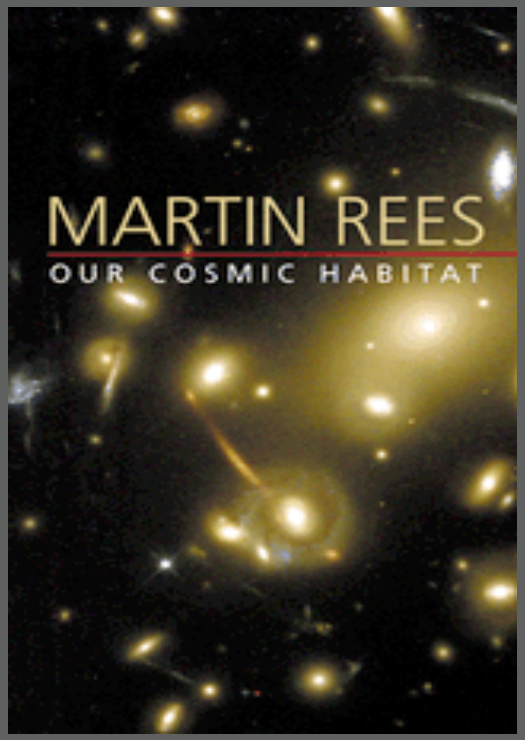
- too large a value for Λ results in no structure and hence no life

- then anthropic considerations mean that the value of Λ we observe will be small [in fundamental units]:
- thus justifying an actual value extremely different from the `natural' one predicted by physics: 120 orders of magnitude

**** making the extremely improbable appear probable***

- the true multiverse project

Our Cosmic Habitat
Martin Rees



Rees explores the notion that our universe is just a part of a vast "multiverse," or ensemble of universes, in which most of the other universes are lifeless. What we call the laws of nature would then be no more than local bylaws, imposed in the aftermath of our own Big Bang. In this scenario, our cosmic habitat would be a special, possibly unique universe where the prevailing laws of physics allowed life to emerge.

The Cosmic Landscape: String Theory and the Illusion of Intelligent Design

Leonard Susskind

Susskind concludes that questions such as "why is a certain constant of nature one number rather than another?" may well be answered by "somewhere in the megaverse the constant equals this number: somewhere else it is that number. We live in one tiny pocket where the value of the constant is consistent with our kind of life. That's it! That's all. There is no other answer to the question".

"The anthropic principle is thus rendered respectable and intelligent design is just an illusion"

The big issue

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.

Note: we are concerned with ***really existing*** multiverses, not potential or hypothetical.

Two central scientific virtues are testability and explanatory power. In the cosmological context, these are often in conflict with each other.

The extreme case is multiverse proposals, where no direct observational tests of the hypothesis are possible, as the supposed other universes cannot be seen by any observations whatever, and the assumed underlying physics is also untested and indeed probably untestable.

In this context one must re-evaluate what the core of science is: can one maintain one has a genuine scientific theory when direct and indeed indirect tests of the theory are impossible?

If one claims this, one is altering what one means by science. One should be very careful before so doing.

Their definition: ***how multiverses should be defined?***

- Note the key distinction between *the collection of all possible universes*, and *ensembles of really existing universes* [essential for anthropic arguments]

- Hence: need to describe both the ***space of possibilities***, and ***distribution functions*** on that space

Issue 1: The choice of these spaces, and their rationale

- what range of possibilities will be contemplated?

Issue 2: The choice of parameters for describing these spaces, and their many possible representations

- the equivalence problem

- **Their non-uniqueness: possible models**

"The space of all possible universes" is not an easily delimited concept: but choice of what we include here determines what we get out of the multiverse concept.

The very description of the space M of possibilities is based on an assumed set of laws of behavior, either laws of physics or meta-laws that determine the laws of physics; without this, we have no basis for setting up a description of ***M***.

Who/what decides on the space of possibilities?

How wide a variation of properties are we prepared to consider in our class of multiverses?

- universes with quite different physics?
- universes with different logic?
- universes allowing magic? [Harry Potter]

- **Their non-uniqueness: realised models**

Realised multiverses are by no means unique, and require the existence of a well-defined and physically motivated distribution function on the space of all possible universes.

Furthermore, a proper measure on these spaces is also needed, so that probabilities can be calculated.

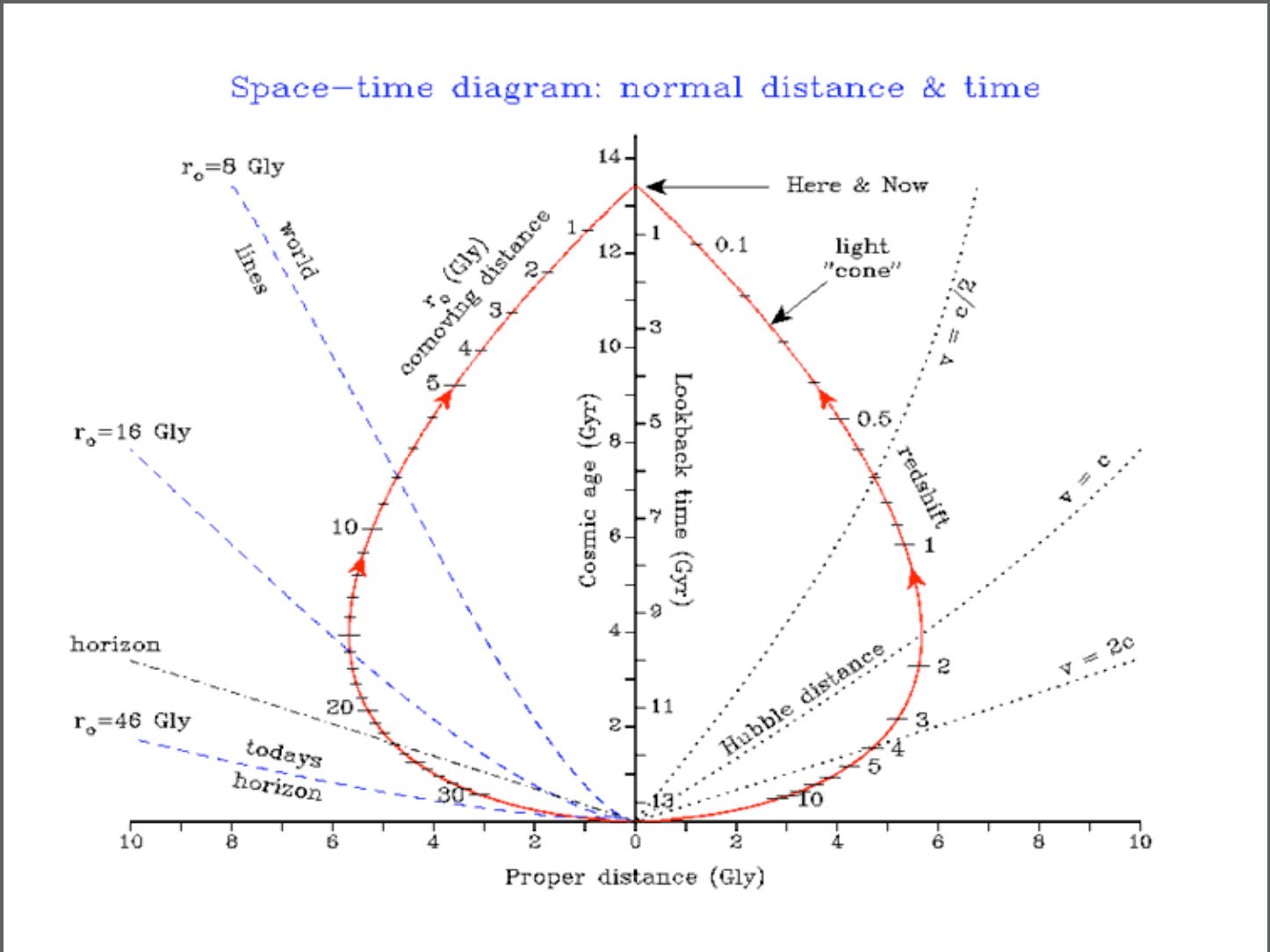
Hence: whence the choice of these functions, and what is their rationale?

One option: there is a unique creation process that generates them

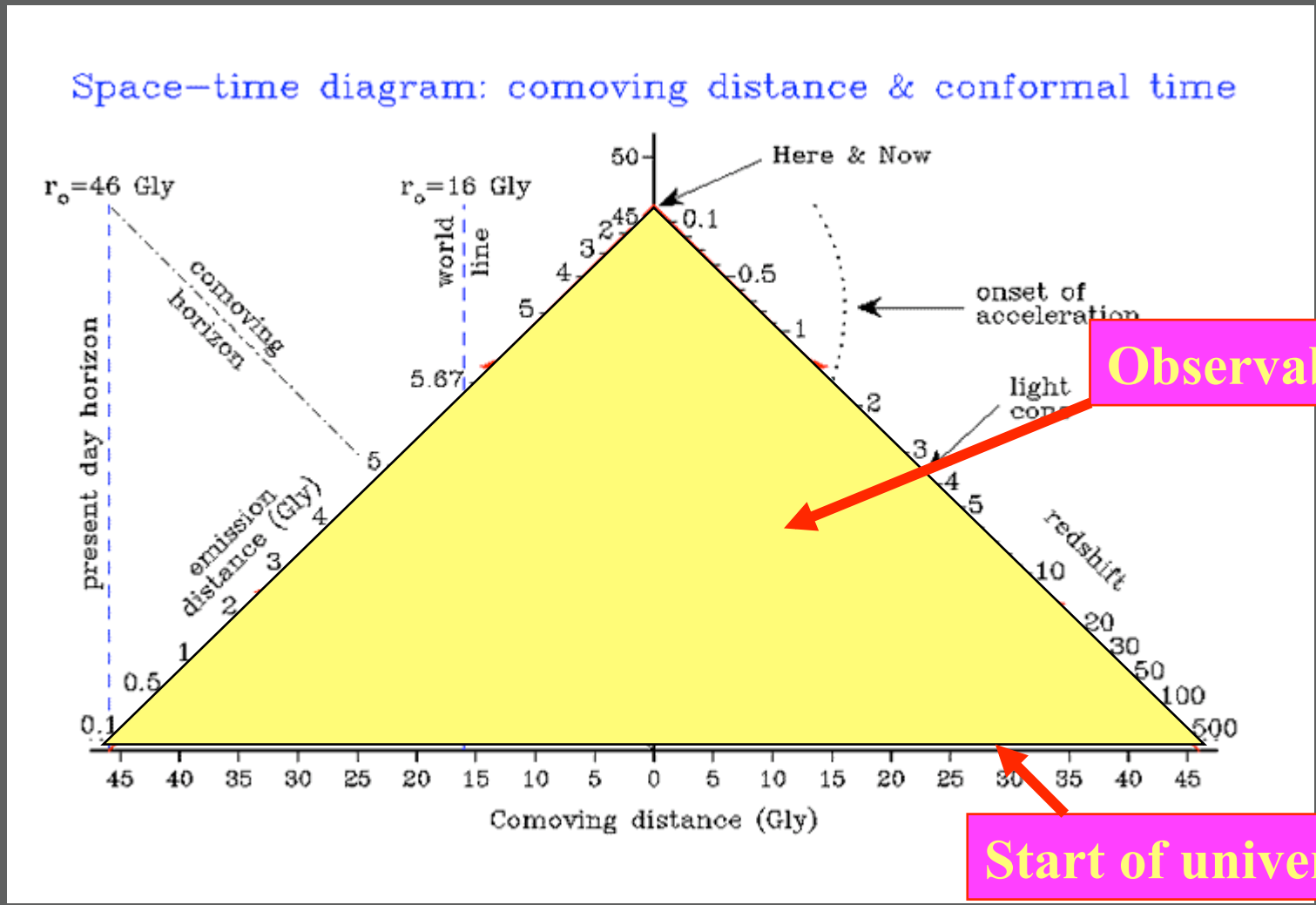
BUT: then how do you test this process?? [LATER]

The key observational point is that the domains considered are beyond the particle horizon and are therefore unobservable.

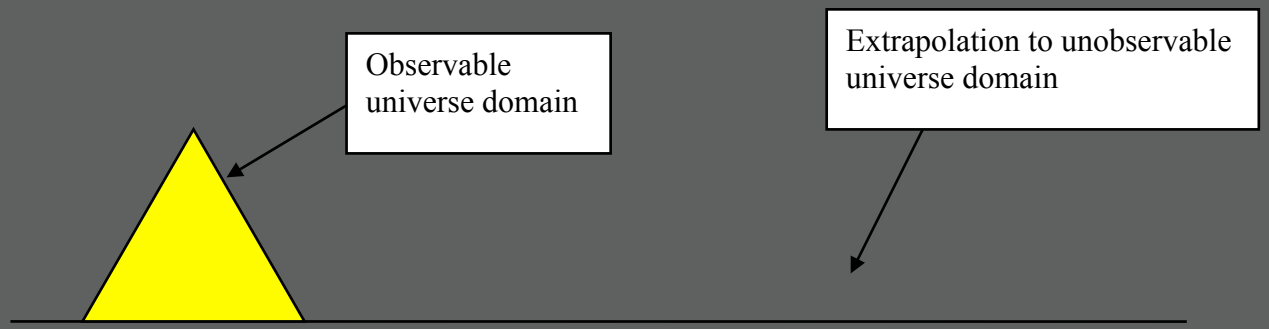
See the diagrams of our past light cone by Mark Whittle (Virginia)



Expand the spatial distances to see the causal structure (light cones at ±45°)



Now it is clear what the observational and causal limits are:



No observational data whatever are available!

Better scale:

The assumption is we that can extrapolate to 100 Hubble radii, 10^{1000} Hubble radii, or much much more (`infinity')
– go to Cape Town and we haven't even started!

Given this situation, what are the arguments and evidence for existence of a multiverse?

1: ***Slippery slope***:

there are plausibly galaxies beyond the horizon, where we can't see then; so plausibly many different expanding universe domains where we can't see them

Untestable extrapolation; assumes continuity that may or may not be true. Outside where we can see, there might be (a) an FRW model, (b) chaotic inflation, (c) a closed model, (d) an island universe. No test can be done to see which is the case .

If each step in a chain of evidence is well understood and tenable, then indirect evidence carries nearly as much weight as direct evidence. But not all the steps in this chain are tenable.

If employed leads to the old idea of spatial homogeneity forever (`The Cosmological Principle') rather than the multiverse of chaotic cosmology with domain walls separating phases.

2: ***Implied by known physics*** that leads to chaotic inflation

The key physics (Coleman-de Luccia tunneling) 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. The physics is hypothetical rather than tested

Known Physics → **Multiverse** ?? NO!

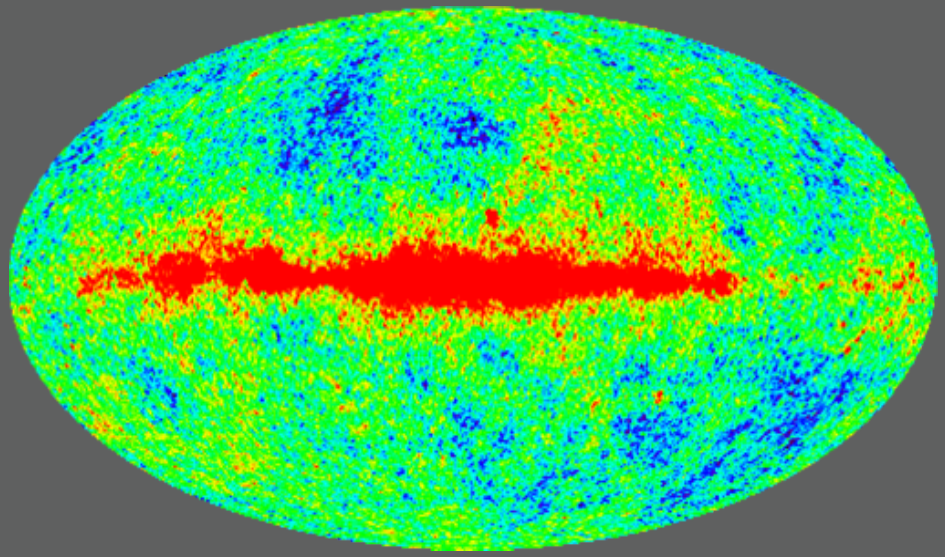
Known Physics → **Hypothetical Physics** → **Multiverse**

Major Extrapolation

It is a great extrapolation from known physics.

This extrapolation is untestable: it may or may not be correct.

3: *Implied by inflation, which is justified by CBR anisotropy observations*



- it is implied by some forms of inflation but not others; inflation is not yet a well defined theory (and not a single scalar field has yet been physically detected). Not all forms of inflation lead to chaotic inflation.

4: Implied by *probability argument: the universe is no more special than need be to create life.*

Hence the observed value of the Cosmological constant is confirmation [Weinberg]

But the statistical argument only applies if a multiverse exists; it is simply inapplicable if there is no multiverse.

In that case we only have one object we can observe; we can do many observations of that one object, but it is still only one object (one universe), and you can't do statistical tests if there is only one existent entity

We don't know the measure to use; but the result depends critically on it

This is in fact a *weak consistency test* on multiverses, that is indicative but not conclusive (a probability argument cannot be falsified). *Consistency tests* must be satisfied, but they are not *confirmation* unless no other explanation is possible

5: Can be *disproved if we observer closed spatial sections as implied by k = +1*

The claim is that only negatively curved FRW models can emerge in a chaotic inflation multiverse.

5a: because Coleman-de Luccia tunneling only gives k = -1;

But that claim is already disputed, there are already papers suggesting k=+1 tunneling is possible

- indeed it depends on a very specific speculative mechanism, which has not been verified to actually work, and indeed such verification is impossible.

5b: because the spatial sections are then necessarily closed and are all there is that is, if they extend far enough

- **but we could live in high density lump imbedded in a low density universe: the extrapolation of k=+1 may not be valid**

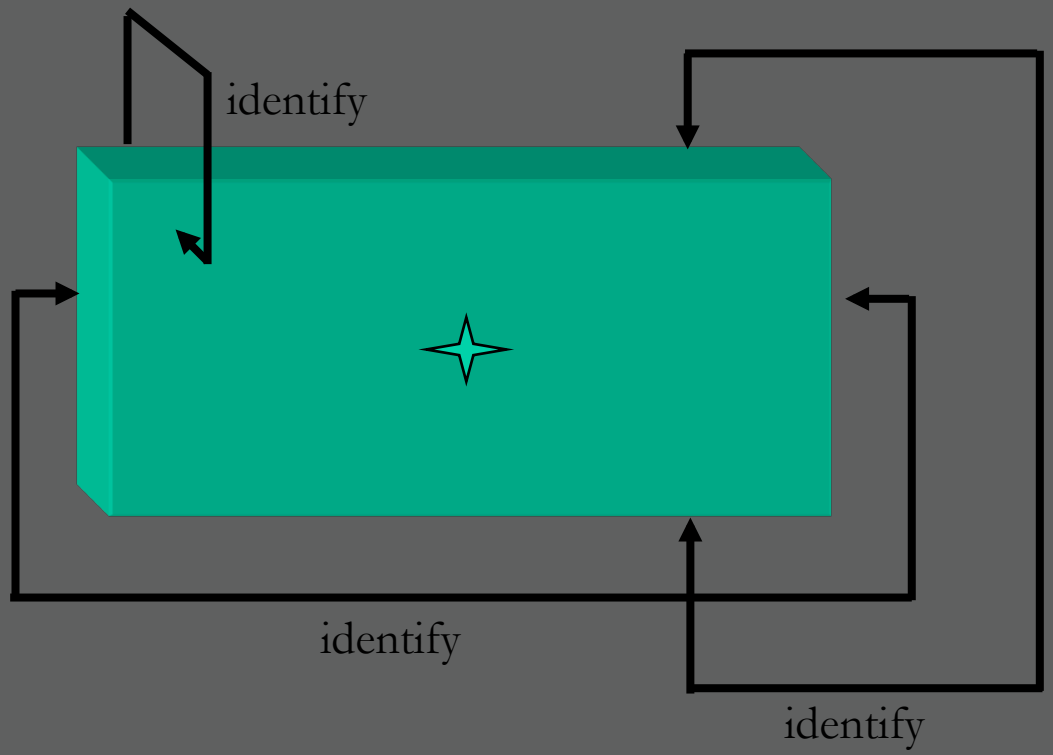
Neither conclusive!

However:

Chaotic inflation version can be *disproved if we observer a small universe: have already seen round the universe. Therefore spatially closed:*

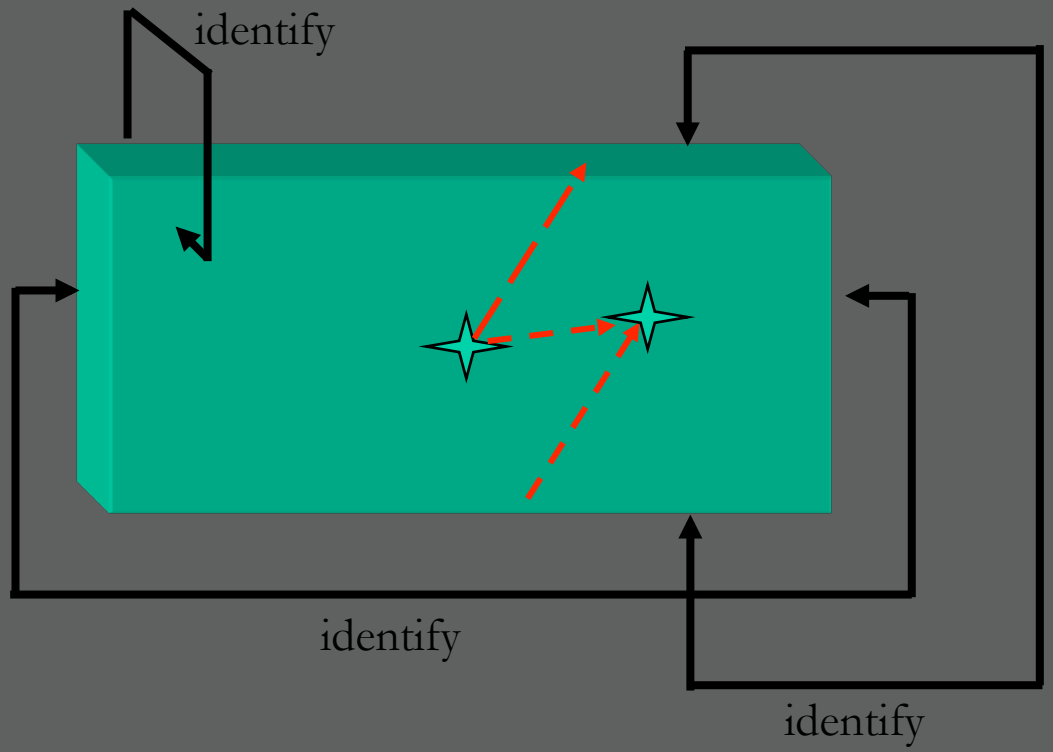
- **Can search for identical circles in the CBR sky, also CMB low anisotropy power at large angular scales (which is what is observed).**
- **A very important test as it would indeed disprove the chaotic inflation variety of multiverse.**
- **But not seeing them would not prove a multiverse exists. Their non-existence is a necessary but not sufficient condition .**

Example of Small Universes



Torus topology (k=0)

Example of Small Universes



Multiple images of each other object

6a: It is the only *physical explanation for fine tuning of parameters* that lead to our existence,

- **in particular the value of the cosmological constant**

[n.b. theoretical explanation, not observation]

6b: It results from the theory that "*everything that can happen, happens*" (Lewis, Sciama, Deutsch, Tegmark) as suggested by Feynman QFT approach

[n.b. theoretical explanation, not observation]

Which is more important in cosmology:

theory (explanation) or observations (tests against reality) ?

7: Bubble collisions

If different bubbles collides, we'll see them in the CMB background.

Agreed: but

- don't occur in all multiverse proposals

-not seeing them is not evidence against a multiverse

-If we see seeing such anisotropies, they will be open to other interpretations, e.g. inhomogeneity

- the physics of the interaction is highly speculative and potentially catastrophic

Implication of all the above:

The multiverse idea is not provable either by observation, or as an implication of well established physics. It may be true, but cannot be shown to be true by observation or experiment.

However it does have great explanatory power: it does provide an empirically based rationalization for fine tuning, developing from known physical principles.

Here one must distinguish between explanation and prediction. Successful scientific theories make *predictions*, which can then be tested.

The multiverse theory can't make any predictions because it can explain anything at all.

Any theory that is so flexible is not testable because almost any observation can be accommodated.

For those who believe that the essential ingredient of science is experimental or observational verification, this is very problematic.

Question: are these proposals genuine science?

Do they amount to redefining the nature of science?

If so: we'd better be careful about all the quasi- and psuedo-sciences waiting in the wings.

Whatever weakening of the concept "Science" we may propose will be seized on and claimed by them too. So BEWARE!!

How do we tell what is science? Four view of the nature of scientific proof: and how they relate to these issues.

1 Metaphysical principles of choice (the rational view)

Meta-principles of science underlie our procedures and choices

• Testability, predictions verified, Explanatory power, Unification of explanation, Simplicity (Ockham's razor)

These criteria are all acknowledged as desirable. The point then is that generally in pursuing historical sciences, and in particular in the cosmological context, they will not all be satisfied, and may even lead to opposing conclusions:

Conflicts will inevitably arise in applying criteria for satisfactory cosmological theories, so that one will have to choose between them to some degree; this choice will shape the resulting theory.

The issue is which of the meta-principles of science should be most important? How should we balance them?

2: Based in the process of discovery and development (the process view)

Testing is not simple!

- Hempel (Induction), Kuhn (change of paradigms), Lakatos (scientific research programmes)

-A hard core plus belt of auxiliary hypotheses interposing between the core and the data

- ***Progressing*** or ***decaying*** scientific research programs: making great strides in unification and explanatory power on the basis of observations, or getting more and more complex and baroque and adding more and more auxiliary hypotheses to accommodate the data (`epicycles').

- How did you get there? Is the process a believable process?

3: Based in the power of a scientific elite (the political view)

- Sociologists of science: scientific orthodoxy is based in the beliefs and theories of those who constitute the scientific centre of power, who validate or deny theories according to how they fit their dogmas. Scientific truth is what the elite says it is

Example: Efstafthiou and Lambda

Example: Coles/Ellis and Omega

-- Pioneers and transition figures

Example: the struggle around arXiv

?? Is this the real issue in relation to multiverses and the string theory landscape? [Example: GE and string theory]

Whether it is or not, is this the way we want to go?

4. Based in philosophical agendas or the emotional swaying power of the proposal (a motivational view)

- We rationalise our choices after we have made them for other reasons (lots of neuroscience evidence)

The motivational power of philosophical convictions

The motivational power of emotions - underlies existence of science

- Neuroscience: Emotions underlie rationality (Damasio, Affective Neural Darwinism)

- The myth of rational choice

- Scientific truth is shaped by our philosophical agendas and/or emotional leanings, rationalised afterwards by selective proof

- (e.g. “beauty” as a criterion)

?? Is this an issue in relation to multiverses and the string theory landscape? [e.g. Susskind]

Whether it is or not, is this the way we want to go?

Rational choice: The Metaphysical Criteria:

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

2. Intrinsic explanatory power: (a) logical tightness, (b) scope of the theory --- the ability to unify otherwise separate phenomena, and (c) probability of the theory or model with respect to some well-defined measure;

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

4. Observational and experimental support, in terms of (a) testability: the ability to make quantitative as well as qualitative predictions that can be tested; and (b) confirmation: the extent to which the theory) is supported by such tests as have been made.

It is particularly the latter that characterizes a scientific theory, in contrast to other types of theories claiming to explain features of the universe and why things happen as they do.

It should be noted that these criteria are philosophical in nature in that they themselves cannot be proven to be correct by any experiment. Rather their choice is based on past experience combined with philosophical reflection.

One could attempt to formulate criteria for good criteria for scientific theories, but of course these too would need to be philosophically justified. The enterprise will end in infinite regress unless it is ended at some stage by a simple acceptance of a specific set of criteria.

Criteria of satisfactoriness for theories cannot be scientifically chosen or validated. They are necessary for choosing good cosmological theories; these criteria have to be chosen on the basis of philosophical considerations.

Conflicts between criteria.

These criteria are all acknowledged as desirable. The point then is that generally in pursuing historical sciences, and in particular in the cosmological context, they will not all be satisfied to the same degree, and may even lead to opposing conclusions:

Conflicts will inevitably arise in applying criteria for satisfactory cosmological theories.

Philosophical criteria for satisfactory cosmological theories will in general come into conflict with each other, so that one will have to choose between them to some degree; this choice will shape the resulting theory.

The tenor of scientific understanding may change, altering the balance of what is considered a good explanation and what is not.

An example is the change from supposition of underlying order, expressed in the idea of a Cosmological

Principle, to a broad supposition of generic disordered conditions, embodied in the ideas of inflation.

Associated with this is a shift from making geometric assumptions to providing physical explanatory models.

It is this shift that underlies the major present support for inflation

Progress? Yes!

It has underlain a progressive research programme that has led to many new discoveries

The underlying concept: fine-tuning

Are very special initial conditions or generic primordial conditions more likely to occur?

The present philosophical prediliction for generality does not necessarily reflect the nature of physical reality.

The real universe may or may not be probable. There is no way to PROVE which is the case.

Indeed every indication is that it is NOT probable, and we are running round in circles trying to explain this.

The criteria and multiverses:

The argument that an infinite ensemble actually exists can be claimed to have a certain explanatory economy, although others would claim that Occam's razor has been completely abandoned in favour of a profligate excess of existential multiplicity, extravagantly hypothesized in order to explain the one universe that we do know exists.

Certainly the price is a lack of testability through either observations or experiment, which is usually taken to be an essential element of any serious scientific theory and is the core reason science has had the success it has.

If it is a scientific proposition one needs to be able to show eventually which specific multiverse exists; but there is no observational way to do this. If you can't show in principle which particular one exists, it is doubtful you have shown any one exists.

The idea of a multiverse provides a possible explanation of fine tuning. But it is not uniquely defined, is not scientifically testable apart from some consistency tests, and in the end simply postpones the ultimate metaphysical question

The consistency tests are necessary conditions for specific multiverse proposals, but not themselves proof that the basic multiverse proposal is true. Adopting these explanations is a triumph of theory over testability, but the theories being assumed are not tested or testable.

However the cumulative weight of many such consistency tests may start to be persuasive. If many of them were to be verified, the combined evidence would amount to much more than the sum of the items.

Conclusion:

I conclude that multiverse proposals are good empirically-based philosophical proposals for the nature of what exists, but are not strictly within the domain of science because they are not adequately testable.

I emphasize that there is nothing wrong with empirically-based philosophical explanation, indeed it is of great value, provided it is labeled for what it is.

I suggest that cosmologists should be very careful not make methodological proposals that erode the essential nature of science in their enthusiasm to support specific theories as being scientific, for if they do so, there will very likely be unintended consequences in other areas where the boundaries of science are in dispute.

It is dangerous to weaken the grounds of scientific proof in order to include multiverses under the mantle of `tested science' for there are many other theories standing in the wings that would also like to claim that mantle.

It is a retrograde step towards the claim that we can establish the nature of the universe by pure thought, and don't then have to confirm our theories by observational or experimental tests: it abandons the key principle that has led to the extraordinary success of science.

In fact we can't establish definitively either the existence or the nature of expanding universe domains that are out of sight and indeed out of causal contact with us.

We don't know whether they exist or not. The claim they exist is a belief rather than an established scientific fact. It is a reasonable faith with strong explanatory nature, but a belief none the less.

ON INFINITIES

Often it is claimed there are *physically existing infinities* (of universes, and of spatial sections in each universe) in the multiverse context

(e.g. Vilenkin: *Many Worlds in One: The Search for Other Universes*)

- infinity is an unattainable state rather than a number

(David Hilbert: "the infinite is nowhere to be found in reality, no matter what experiences, observations, and knowledge are appealed to.")

- *completely untestable:* if we could see them, which we can't, we could not count them in a finite time.

TESTING THE TEST

- Standard cosmology (expanding universe)
- Inflationary universe epoch
- Evolutionary theory (Darwin)
- Intelligent Design
- Astrology
- Parapsychology

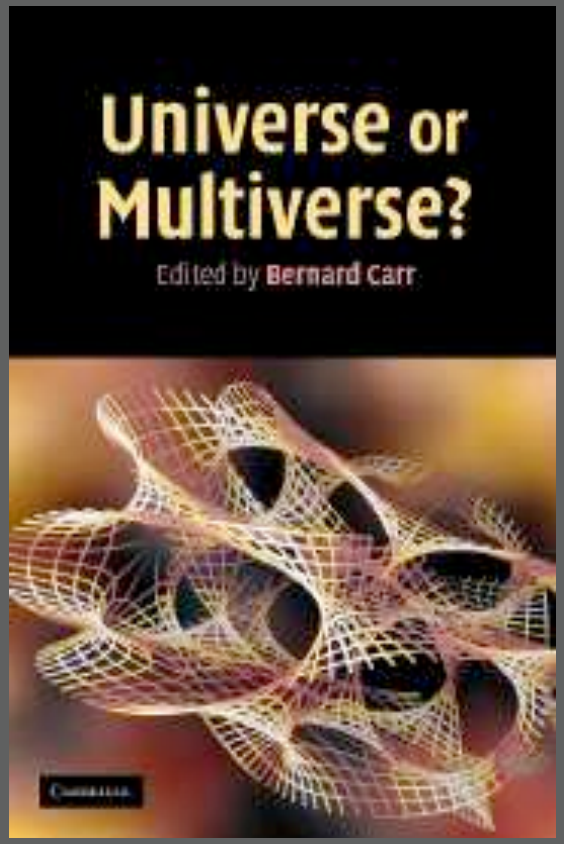
If we have a good definition of `science', it should work satisfactorily in these cases.

Then we can apply it to multiverses, and see what the conclusion is.

Maybe this is too naïve: then what else should we do?

Universe or Multiverse?

Bernard Carr



Recent developments in cosmology and particle physics, such as the string landscape picture, have led to the remarkable realization that our universe - rather than being unique - could be just one of many universes. Since the physical constants can be different in other universes, the fine-tunings which appear necessary for the emergence of life may also be explained. Nevertheless, many physicists remain uncomfortable with the multiverse proposal, since it is highly speculative and perhaps untestable.

Is there a philosophically preferable version of the multiverse idea?

I argue that Lee Smolin's idea of a Darwinian evolutionary process in cosmology [L. Smolin, *The Life of the Cosmos,* Crown Press, 1997] is the most radical and satisfactory one:

- it introduces the idea of Darwinian natural selection into cosmology: an extension of physics fundamentals to include biological principles.

However it is incomplete in several ways.

Possible Universes: The possibility space ***M*** is the set of all possible universes ***m***, each of which can be described by a set of states ***s*** in a state space ***S***. Each universe in ***M*** will be characterised by a set ***P*** of distinguishing parameters ***p***, which are coordinates in ***S***.

Each universe ***m*** in ***M*** will evolve from its initial state to the final state according to the dynamics operative, with some or all of its parameters varying as it does so. Thus each such path in ***S*** (in degenerate cases, a point) is a representative of one of the universes ***m*** in ***M***.

The very description of the space M of possibilities is based on an assumed set of laws of behavior, either laws of physics or meta-laws that determine the laws of physics; without this, we have no basis for setting up a description of ***S*** or ***M***.

Realised Universes: In order to select from ***M*** a set of physically realised universes (a `multiverse'), we need to define a distribution function ***f(m)*** on ***M*** specifying how many times each type of possible universes ***m*** in ***M*** is realised.

The class of models considered is determined by all the parameters held constant (`class parameters'). The models in the class are determined by the parameters allowed to vary (`member parameters'). For continuous parameters we need a volume element $\pi = \Pi_{i,j}\, m_{ij}(m) dp_j(i)$ charaterised by weights $m_{ij}(m)$. The number of universes corresponding to the set of parameter increments $dp_j(I)$ will be

$$dN = f(m)\, \pi$$

Thus: a ***realised ensemble E of universes*** is characterised by a possibility space ***M***, a measure π on ***M***, and a distribution function ***f(m)*** on ***M***.

Fine tuning: *Just Six Numbers* [Martin Rees]

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