The multiverse: conjecture, proof, and science

George Ellis

Talk at Nicolai Fest
Golm 2012

Does the Multiverse Really Exist **?**
Scientific American: July 2011

The idea

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

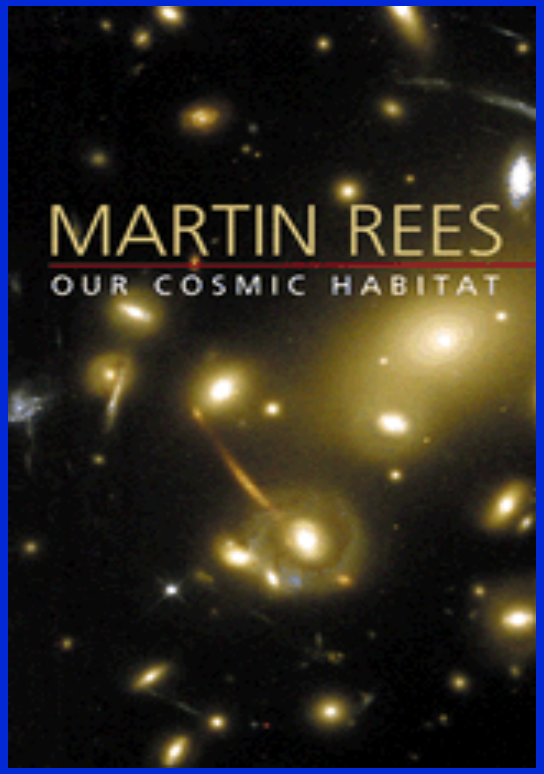
- separate places [Vilenkin, Linde, Guth]
- separate times [Smolin, cyclic universes]

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

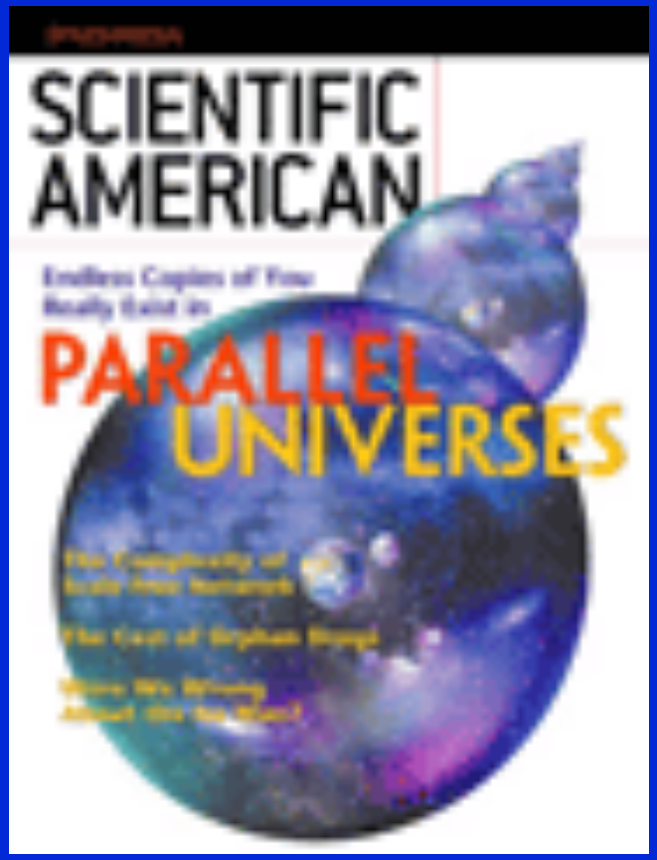
- totally disjoint [Sciama, Tegmark]

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.



Scientific American

May 2003 issue

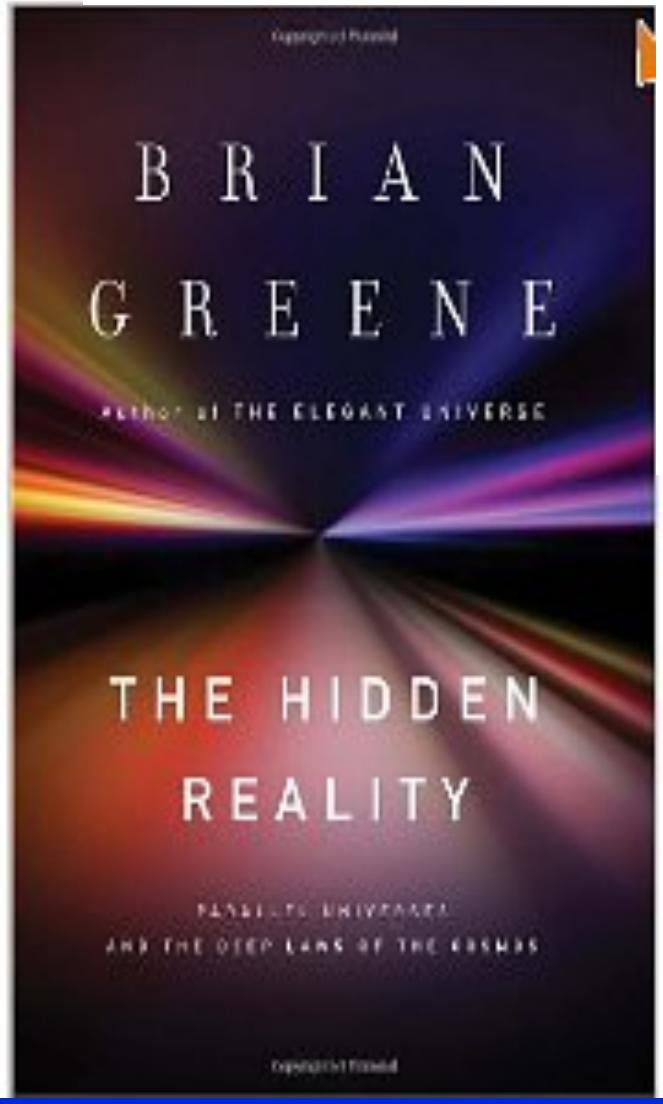
COSMOLOGY

"Parallel Universes:

Not just a staple of science fiction,

other universes are a direct implication of cosmological observations"

By Max Tegmark



Brian Greene:
The Hidden Reality

Parallel Universes and
The Deep Laws of the Cosmos

Varieties of Multiverse

Brian Greene (*The Hidden Reality*) advocates nine different types of multiverse:

1. Invisible parts of our universe
2. Chaotic inflation
3. Brane worlds
4. Cyclic universes
5. Landscape of string theory
6. Branches of the Quantum mechanics wave function
7. Holographic projections
8. Computer simulations
9. All that can exist must exist – "grandest of all multiverses"

They can't all be true! – they conflict with each other.

10. Maybe none of the above – there is just one universe.

The motivation for multiverses

1. - claimed as the inevitable outcome of the physical originating process that generated our own universe

   [e.g. An outcome of the chaotic inflationary scenario]

2. - seen as the result of a philosophical stance underlying physics: "everything that can happen happens"

   [The logical conclusion of the Feynman path integral approach to quantum theory]

3. - proposed as an explanation for why our universe appears to be fine-tuned for life and consciousness

Fine tuning: The Anthropic Issue

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

- as regards the laws of physics [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

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

Application: *explaining Cosmological constant*

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

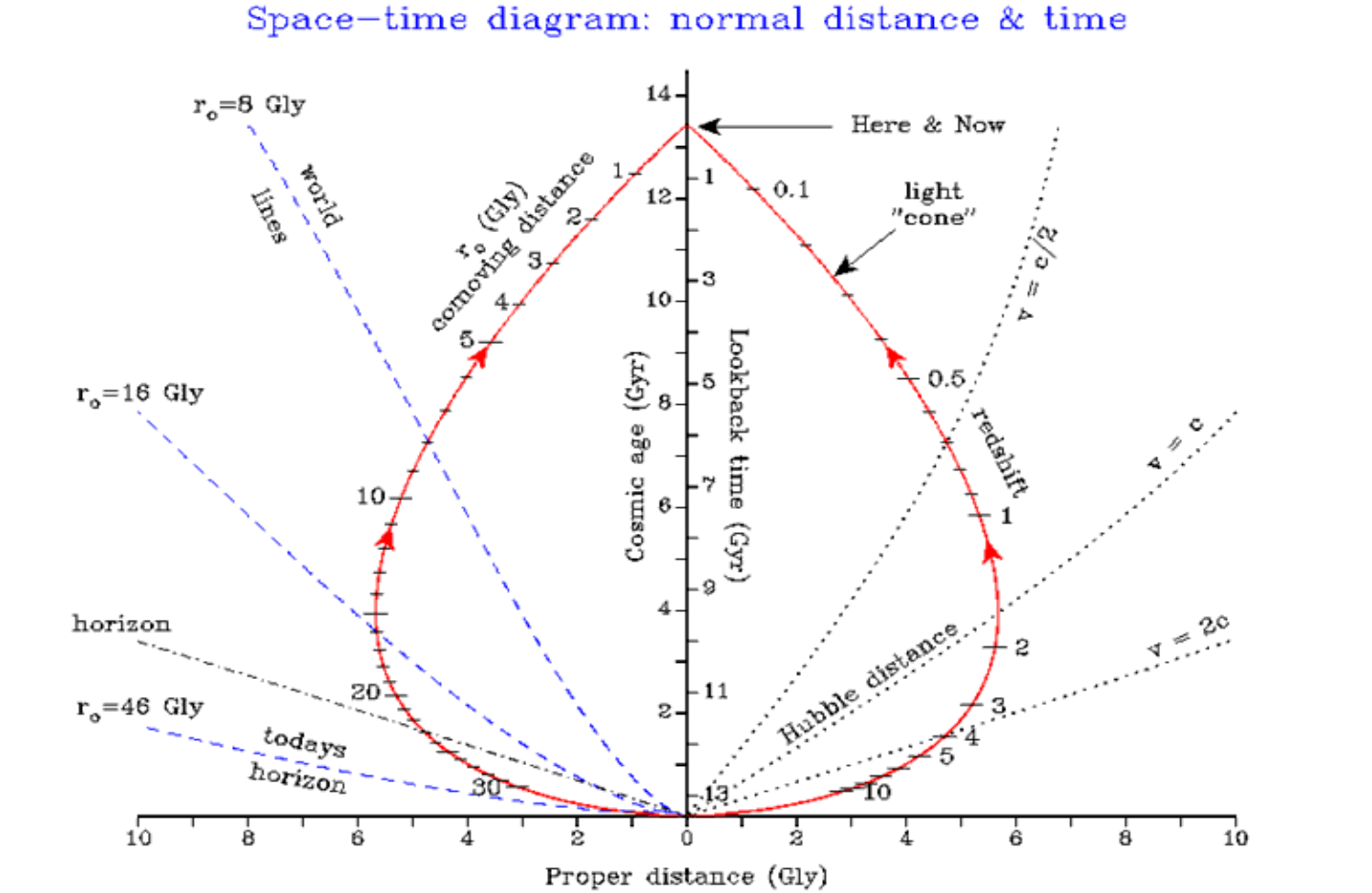
- then anthropic considerations mean that the value of Λ we observe will be small [in fundamental units]:
- thus justifying an actual value extremely different from the `natural' one predicted by physics: 120 orders of magnitude

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

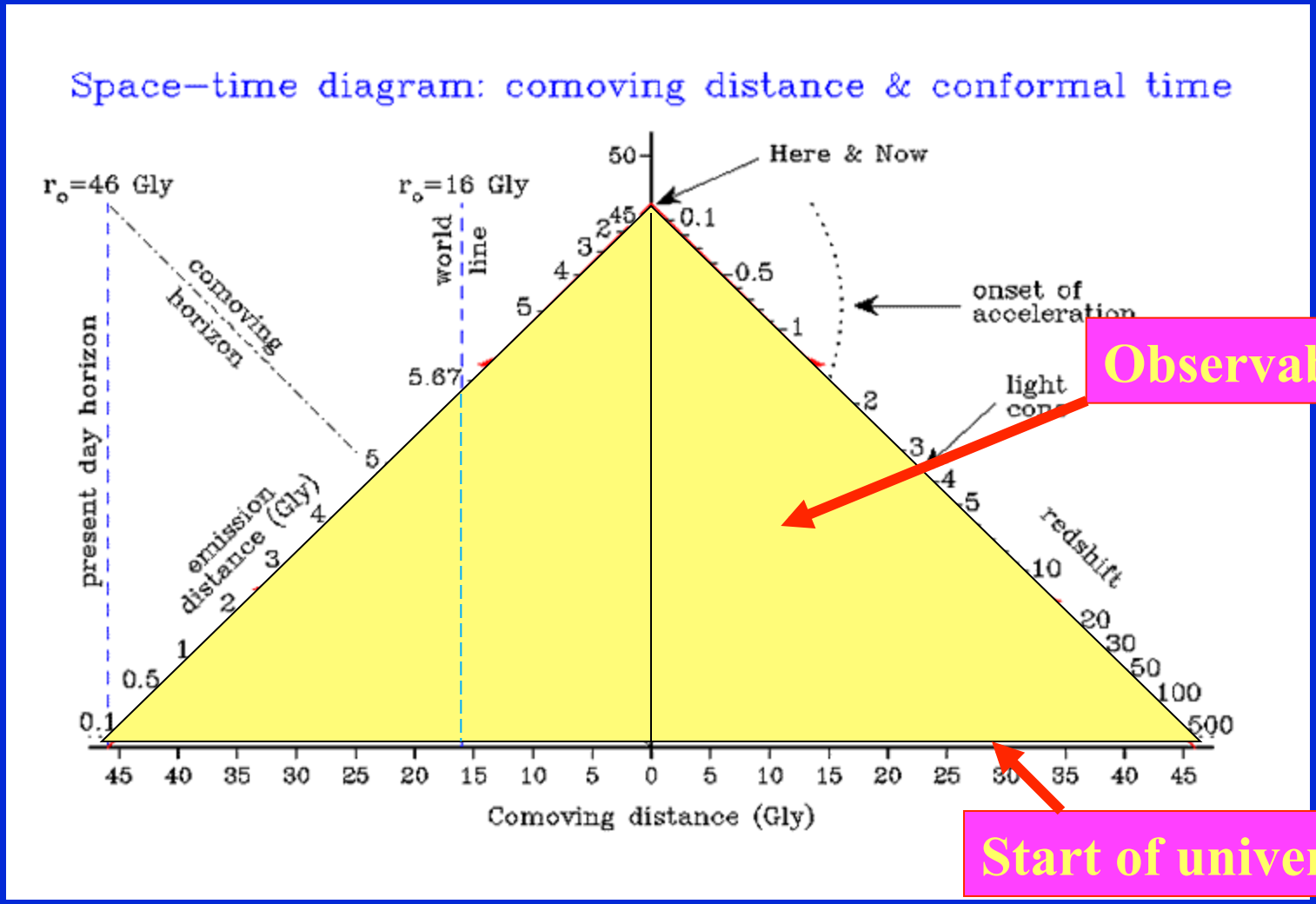
- the true multiverse project

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

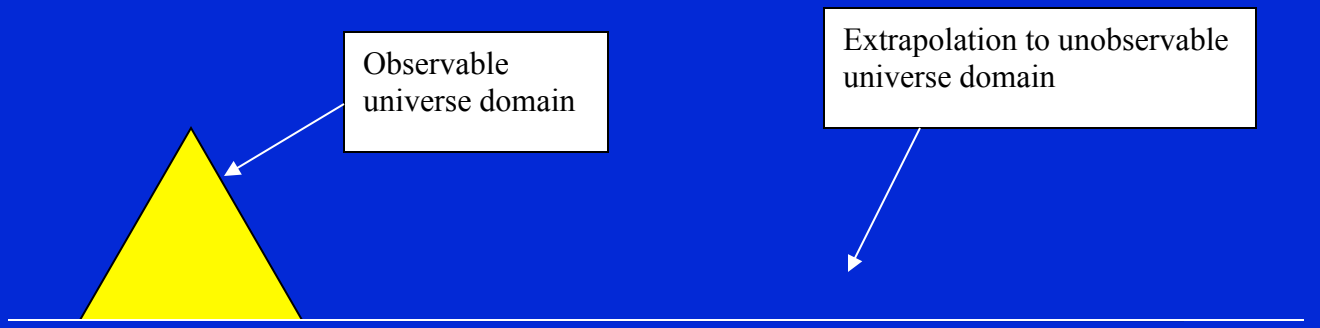
See the diagrams of our past light cone by Mark Whittle (Virginia)



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

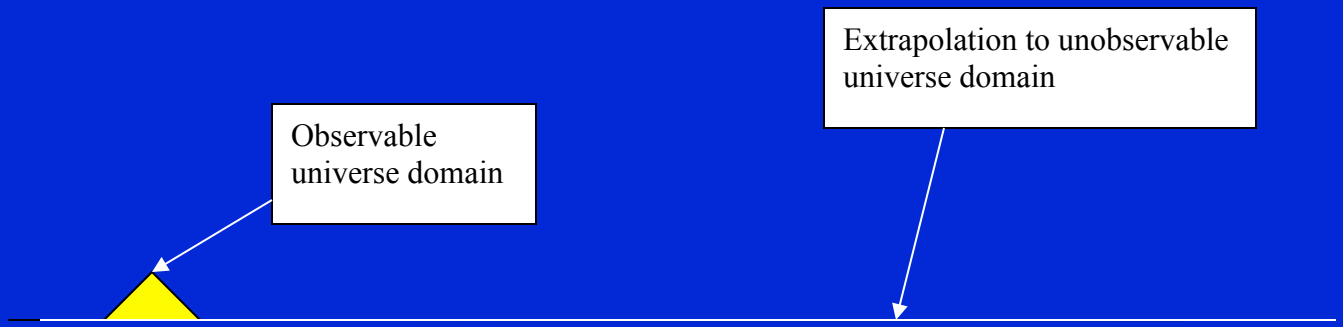


Now it is clear what the observational and causal limits are:



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 inevitable, then indirect evidence carries nearly as much weight as direct evidence. But not all the steps in this chain are inevitable.

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, 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.

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.

The Top 10^{500} Reasons Not to Believe in the Landscape

T Banks: arXiv:1208.5715

The String Landscape is a fantasy. We actually have a plausible landscape of minimally supersymmetric AdS_4 solutions of supergravity modified by an exponential superpotential.

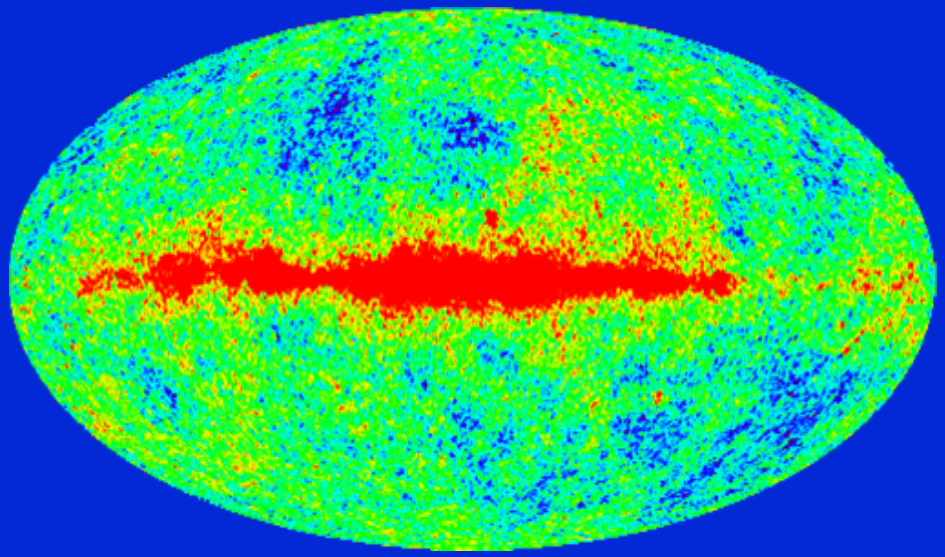
None of these solutions is accessible to world sheet perturbation theory. If they exist as models of quantum gravity, they are defined by conformal field theories, and each is an independent quantum system, which makes no transitions to any of the others. This landscape has nothing to do with CDL tunneling or eternal inflation.

A proper understanding of CDL transitions in QFT on a fixed background dS space, shows that the EI picture of this system is not justified within the approximation of low energy effective field theory. The cutoff independent physics defined by the Euclidean admits only a finite number of these ideas to a quantographic principle CDL transitions in dS space, from eternal inflation.

Whether one agrees or not: this analysis shows that the supposed underlying physics is certainly not well established.

Theories of Eternal Inflation (EI) have to rely too heavily on the anthropic principle to be consistent with experiment. Given the vast array of effective low energy field theories that could be produced by the conventional picture of the string landscape one is forced to conclude that the most numerous anthropically allowed theories will disagree with experiment violently.

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.**
- **Not all forms of inflation lead to chaotic inflation.**
- ***For example inflation in small closed universes***

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

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

In fact no value of the cosmological constant can prove a multiverse either exists or does not exist.

This is elementary logic!

1. If M => L, it does not follow that L => M

2. If M => L only probabilistically, it does not follow that {not L} => {not M}

although it may shorten the odds -

IF there is a valid context in which probability applies.

There is no value of Λ that PROVES a multiverse exists

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 determine there are closed spatial sections because curvature is positive: 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 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!

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

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

Valid supportive argument, but not proof

[n.b. theoretical explanation, not observation]

7: It results from the theory that "*everything that can happen, happens*" (Lewis, Sciama, Deutsch) 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) ? Do we drop the need for testing?

CAVEAT 1: DISPROOF possibility?

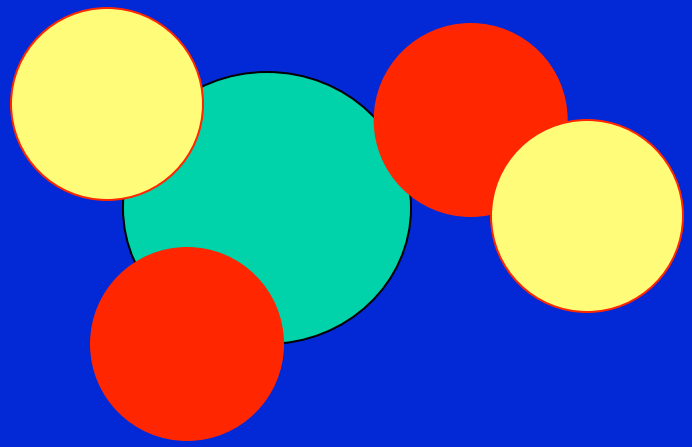
Chaotic inflation version can be *disproved if we observer a small universe: have already seen round the universe. Therefore spatially closed:*

- **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 .**

CAVEAT 2: PROOF possibility?

Proof of existence: Multiverse collisions?

- Bubbles in chaotic inflation might collide if rate of nucleation is large relative to rate of expansion

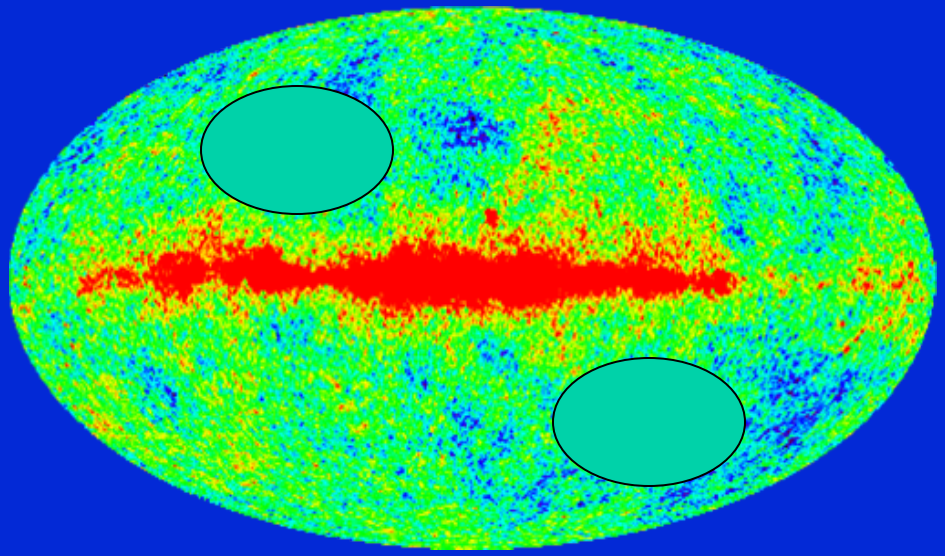


-Observable in principle by circles in CMB sky

-Suggested it might have already been seen

-But very disputed

Implied by anomalous filled circles in CBR anisotropy observations ??



- **Would be pretty convincing if fine structure constant were different within such circles**

But then you are in danger of causing chaotic inflation to come to an end (when all the compact comoving inflationary expansion space is used up)

Issue 1: The claimed existence of *physically existing infinities*

- 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.")

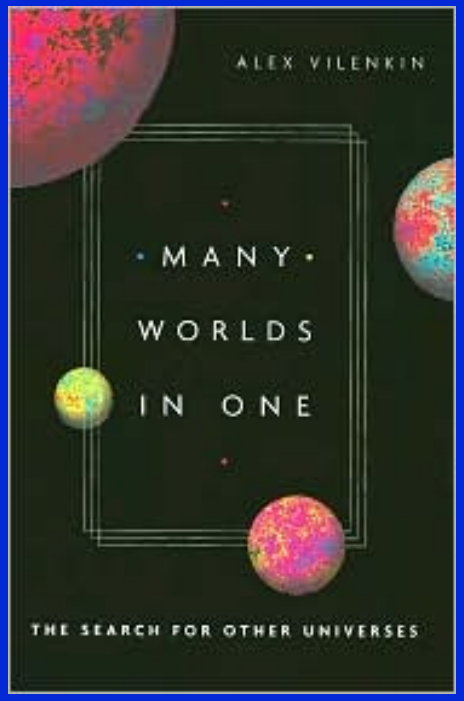
not a scientific statement – if science involves testability by either observation or experiment.

It is a huge act of hubris to extrapolate from one small domain to infinity – NEVER encountering a limit

(remember the conformal diagram;
problems with measure).

Many Worlds in One: The Search for Other Universes

Alex Vilenkin

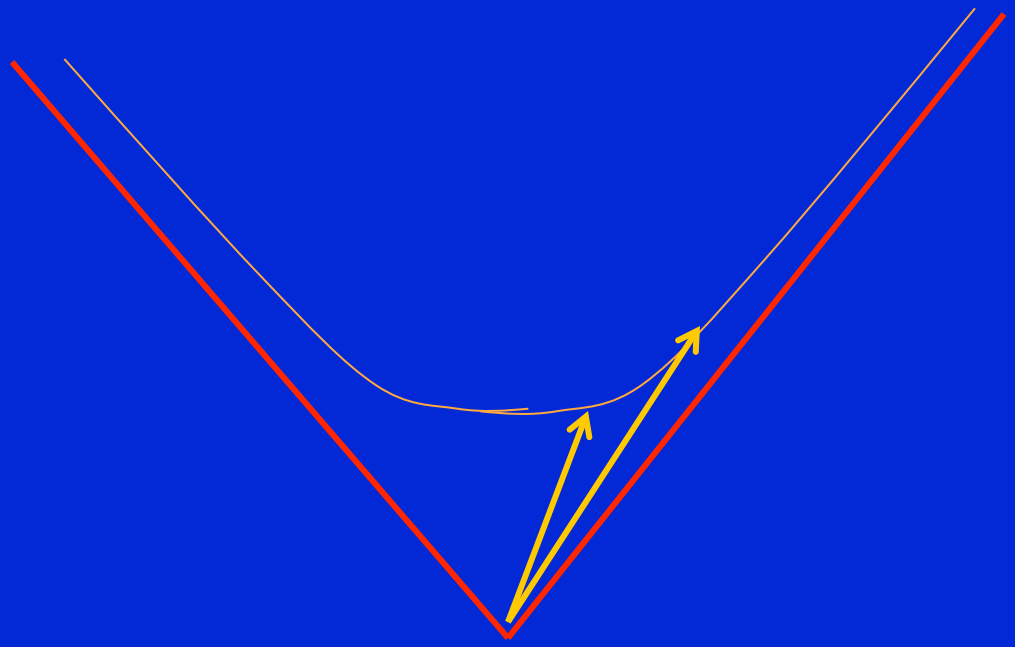


“He goes on to posit that our universe is but one of an infinite series, many of them populated by our "clones." Vilenkin is well aware of the implications of this assertion: "countless identical civilizations [to ours] are scattered in the infinite expanse of the cosmos. With humankind reduced to absolute cosmic insignificance, our descent from the center of the world is now complete.”

Infinity from tunnelling?

Susskind et al: arXiv:hep-th/0505232

Ellis and Stoeger: arXiv:1001.4590



These are the same proper time:
So an infinite space section appears at once

Infinity from tunnelling?

Susskind et al: arXiv:hep-th/0505232

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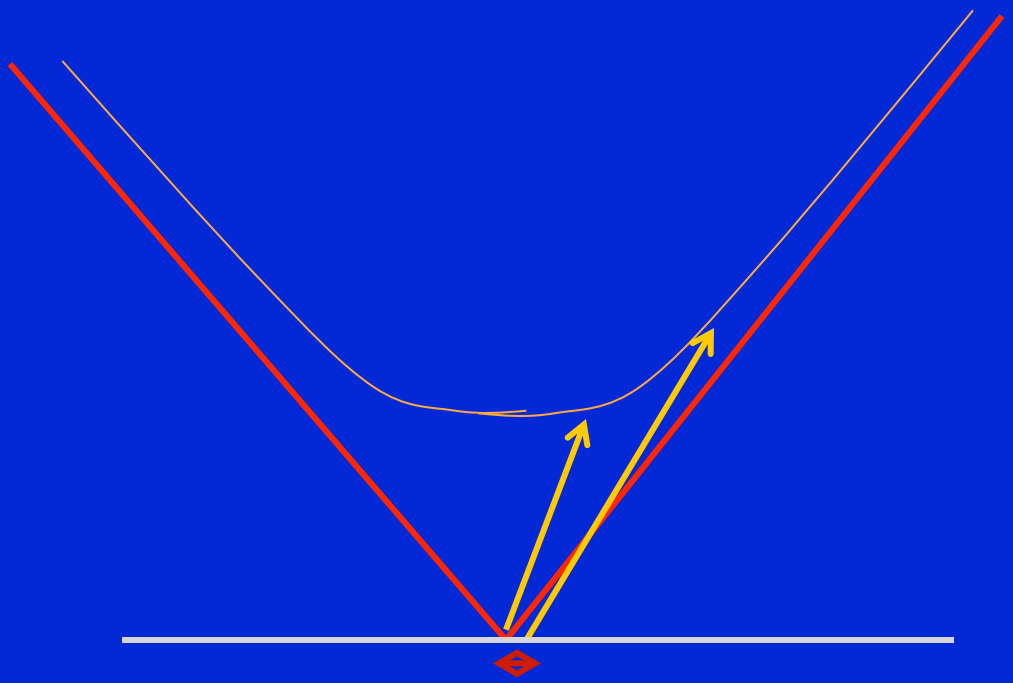


Not true if we remember that the origin can't be exactly a point: takes an eternity to complete, no matter how small the nucleus is

Issue 2: Problem of vacuum energy: QFT vacuum energy suggests Λ huge, discrepant with GR if vacuum gravitates

* MAJOR PROBLEM *

Is multiverse only solution?

Vacuum does not gravitate if we use ***trace free Einstein equations*** plus separate conservation equations ("unimodular gravity")

Solves profound contradiction arising between WFT and EFE is we join them in the obvious way

Then vacuum does not gravitate

$$R_{ab} - \tfrac{1}{2} R\, g_{ab} + \Lambda\, g_{ab} = \kappa\, T_{ab} \qquad (1)$$

(10 equations) implies

$$T^{ab}{}_{;b} = 0 \qquad (2)$$

Instead, take trace free part:

$$R_{<ab>} - \tfrac{1}{2} R\, g_{<ab>} + \Lambda\, g_{<ab>} = \kappa\, T_{<ab>}$$

which is

$$R_{ab} - \tfrac{1}{4} R\, g_{ab} = \kappa\,(T_{ab} - \tfrac{1}{4} T\, g_{ab}) \qquad (3)$$

(9 equations) and assume (2) separately

Recovers (1): but now Λ is a constant of integration and has nothing to do with vacuum energy: which does not gravitate [Weinberg 1989]

Einstein tried this in 1919: but used wrong form

4 possibilities:

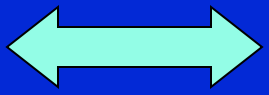
$G_{ab} = \kappa T_{ab}$ (a)

$G_{<ab>} = \kappa T_{ab}$ (b)

$G_{ab} = \kappa T_{<ab>}$ (c)

$G_{<ab>} = \kappa T_{<ab>}$ (d)

Only first and last OK

Last solves GR  QFT incompatibility!

Cosmology ok: even though only inertial mass density in EFE;
Ok at junction with stars [arXiv:1008.1196]

- Related to Unimodular gravity [Finkelstein, Unruh]
- Variation principle? [Alvarez arXiv:1204.6162]

What does QFT version of gravity say?

- **[Feynman, Deser, Weinberg, Zee]**

- Should also give trace free version!
- Because graviton is symmetric trace free

- Needs to be revisited
- Assume energy momentum conservation separate from gravity equations
- Should get only trace free equations as the graviton can't get a handle in trace equation
- E.g. $L = T^{ab} h_{ab} = T^{ab} h_{<ab>} = T^{<ab>} h_{<ab>}$

- **Should necessarily give Trace Free version of EFE**
- **- these have a good claim to be the correct equations**

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. Continuaton beyond horizon is fine – but just the same old universe! (cf horizon on earth)

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 unique predictions because it can explain anything at all.

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

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.

Susskind explicitly states the criteria for scientific theories should be weakened [Kragh 1208:5215]

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

Criteria for a scientific theory

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 .**

These will conflict with each other. You have to choose!

It is particularly the last that characterizes a scientific theory, in contrast to other types of theories

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.

There are many other theories waiting at the door –wanting to be called science (astrology, Intelligent Design, etc)

Implications:

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 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.

AFTERWORD ON SIMULATED UNIVERSES

I am astounded that serious scientists and philosophers can propose that the universe could be a computer simulation (Bostrom, Greene)

It is totally impracticable from a technical viewpoint, and ignores the way the human mind is bodily-embedded and not an algorithmic computer process

It raises far more questions than it answers

- **Where is this computer?**
- **How did it come into being?**
- **Why does it not crash every few seconds?**
- **How could this be proved to be the case – what evidence is there? How could it be disproved?**

Protagonists seem to have confused science fiction with science. Late night pub discussion is not a viable theory.

Is there a philosophically preferable version of the multiverse idea?

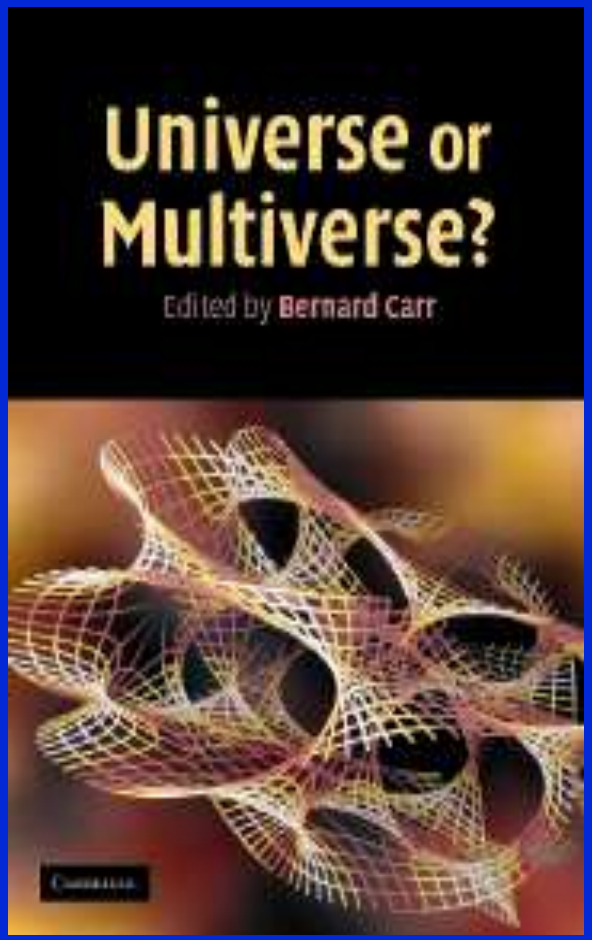
I argue that Lee Smolin's idea of a Darwinian evolutionary process in cosmology [L. Smolin, *The Life of the Cosmos,* Crown Press, 1997] is the most radical and satisfactory one:

- 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.

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.

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

Leonard Susskind

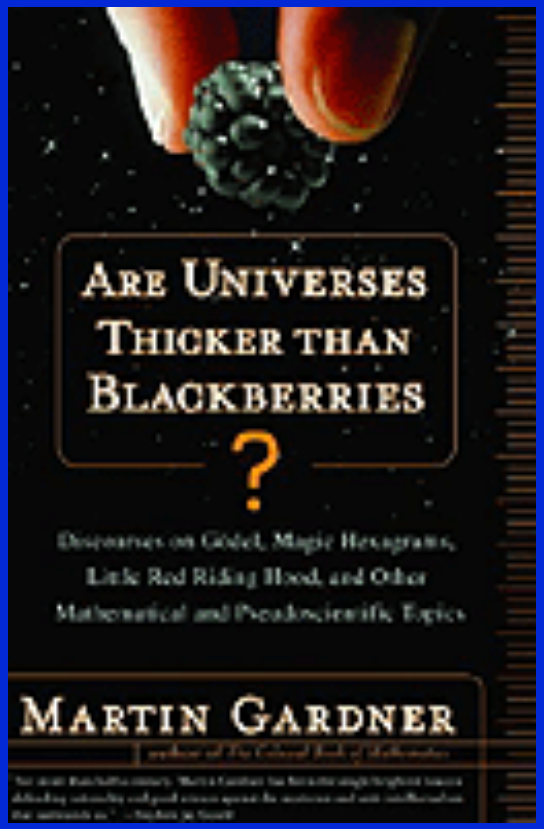
Susskind concludes that questions such as "why is a certain constant of nature one number rather than another?" may well be answered by "somewhere in the megaverse the constant equals this number: somewhere else it is that number. We live in one tiny pocket where the value of the constant is consistent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

Confuses particle and event horizons

s rendered

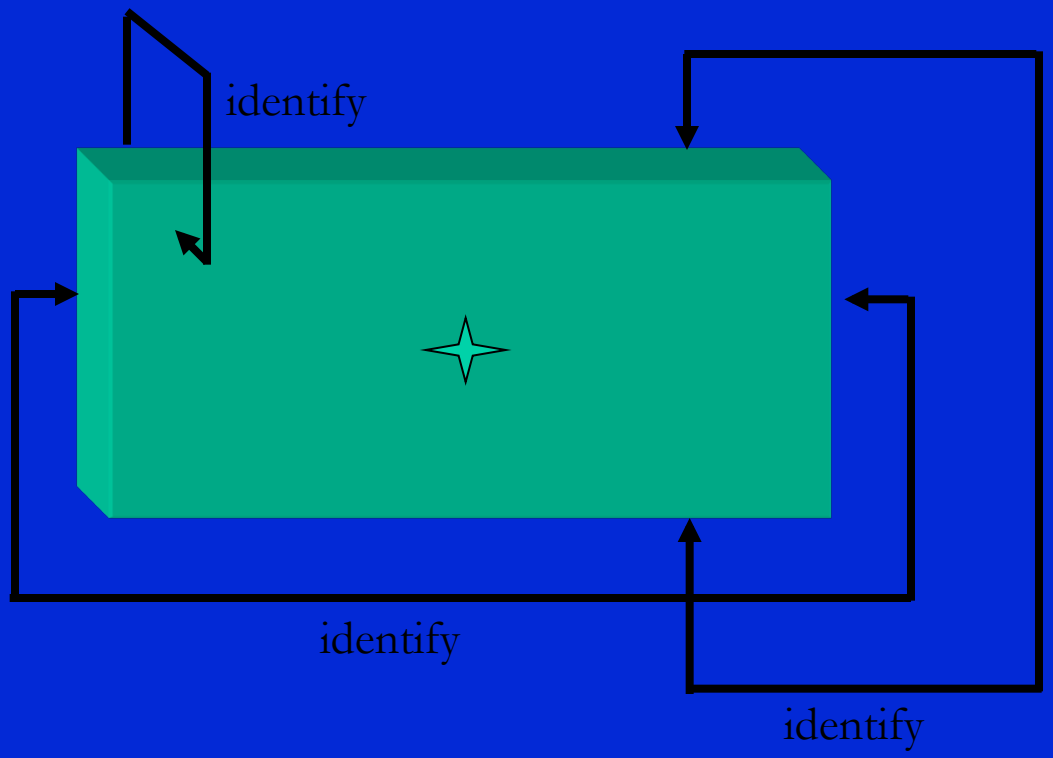
gn is just an illusion"

Are Universes Thicker Than Blackberries?, by Martin Gardner



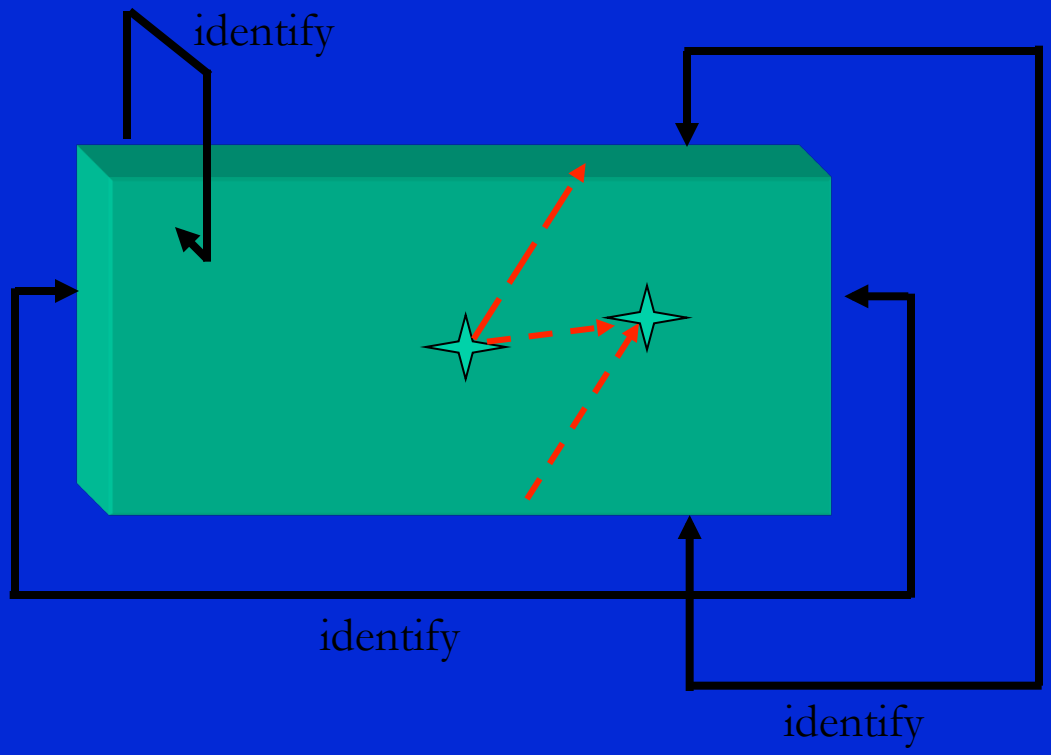
One of the most astonishing recent trends in science is that many top physicists and cosmologists now defend the wild notion that not only are universes as common as blackberries, but even more common. Gardner goes straight to the point: the scientists who say this have given no evidence for believing that the possible worlds other than this one, useful though they may be as fictions, have real existence.

Example of Small Universes



Torus topology (k=0)

Example of Small Universes



Multiple images of each other object

What is needed to change the situation?

- **Determine a viable set of criteria/ procedures for what makes a theory scientific**
- **Find what methods can adequately justify unobservable entities**

- **Apply to the multiverse case**

- **Apply to other contentious cases (astrology, Intelligent Design) to see how they pan out**

- **Put the enterprise on a solid philosophical basis!**

[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]