Observational Selection Effects in Quantum Cosmology

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Abstract

Scientific theories need to be testable by observations, say using Bayes’ theorem. A complete theory needs at least the three parts of dynamical laws for specified physical variables, the correct solution of the dynamical laws (boundary conditions), and the connection with observations or experience or conscious perceptions (laws of psycho-physical parallelism). Principles are proposed for Bayesian meta-theories. One framework that obeys these principles is Sensible Quantum Mechanics (SQM), which is discussed. In principle, it allows one to test between single-history and many-worlds theories, and to discuss threats to certain theories from fake universes and Boltzmann brains. The threat of fake universes may be dismissed if one doubts the substrate-independence of consciousness, which seems very implausible in the SQM framework. Boltzmann brains seem more problematic, though there are many conceivable solutions. SQM also suggests the possibility that past steps along our evolutionary ancestry may be so rare that they have occurred nowhere else within the part of the universe that we can observe.
1 Goals and criteria for scientific theories

I see science as having the following goals:

1. Theories to explain observations
2. Observation-weighted probabilities for these theories
3. Predictions for these theories
4. Understanding of these theories

A complete theory or model of the universe needs at least three parts:

1. Complete set of physical variables (e.g., the arguments of a wavefunction or quantum state) and dynamical laws (e.g., the Schrödinger equation, or the action for a path integral)
2. The correct solution of the dynamical laws (e.g., the wavefunction or quantum state of the universe)
3. The connection with observation or experience (e.g., the laws of psycho-physical parallelism)

Item 1 alone is called a TOE or ‘theory of everything,’ but it is not complete. Even 1 and 2 alone are not complete, since they by themselves do not logically determine what, if any, conscious experiences occur in a universe.

One can do a Bayesian analysis for the epistemic probabilities of theories, which include the following elements:

1. Prior probabilities $p_i \equiv p(T_i)$ for theories $T_i$
   - Necessarily subjective (in my view)
   - Perhaps favoring simplicity, e.g., $p_i = 2^{-n(T_i)}$, where $n(T_i)$ is an ordering of the theories in increasing order of complexity
   - Simplicity itself seems subjective

2. Conditional probabilities $L_{ij} \equiv P(O_j|T_i)$ of observations $O_j$ given theories $T_i$ (the likelihoods of the theories given the observations)

3. Posterior probabilities

$$P_{ij} \equiv P(T_i|O_j) = \frac{P(T_i\&O_j)}{P(O_j)} = \frac{p(T_i)P(O_j|T_i)}{\sum_k p(T_k)P(O_j|T_k)} = \frac{p_i L_{ij}}{\sum_k p_k L_{kj}} \quad (1)$$
In theories giving many observations, it is controversial what the conditional probabilities $L_{ij} \equiv P(O_j|T_i)$ should be taken to be. Is $L_{ij}$ the probability that $O_j$ occurs somewhere in theory $T_i$? In classical mechanics, this would be $L_{ij} = 1$ if $O_j$ occurs and $L_{ij} = 0$ if not. In conventional quantum mechanics, this would be $L_{ij} = \langle \psi_i | P_{O_j} | \psi_i \rangle$, where $|\psi_i\rangle$ is the quantum state given by the theory $T_1$ and $P_{O_j}$ is the projection operator onto the observation $O_j$.

This proposal for $L_{ij}$ would not give observational distinctions between different theories all giving $L_{ij} = 1$. If $T_i$ gives a universe large enough, many $O_j$’s would give $L_{ij} \approx 1$. Then $P_{ij} \equiv P(T_i|O_j)$ would be highest for theories with the highest $p_i \equiv p(T_i)$, e.g., for the simple theory that all $O_j$’s certainly exist, with essentially no influence from observations.

But if some observations occur more in some theory, surely they should be assigned higher conditional probabilities in that theory. E.g., suppose $T_1$ predicts 1 observation of $O_1$ and $10^6$ observations of $O_2$, whereas $T_1$ predicts $10^6$ observations of $O_1$ and 1 observation of $O_2$. Then surely $L_{11} < L_{21}$. To accomplish this, one might restrict to theories $T_i$ giving

$$\sum_j L_{ij} \equiv \sum_j P(O_j|T_i) = 1, \tag{2}$$

so the total probability of all observations is 1 for each theory $T_1$.

One might expand this rule to a set of principles for Bayesian meta-theories:

1. **Prior Alternatives Principle**: The set of alternatives to be assigned conditional probabilities by theories should be chosen logically prior to the observation to be used to test the theories.

2. **Normalization Principle**: The sum of the conditional probabilities each theory assigns to all of the alternatives in the chosen set should be unity.

3. **Conscious Anthropic Principle**: The alternatives ideally should be chosen to be conscious perceptions or observer-moments.

## 2 Sensible Quantum Mechanics

Conventional quantum mechanics does not seem to obey these principles, but *Sensible Quantum Mechanics* or *Mindless Sensationalism* does. In it, there is a *quantum world* (what one might call the physical world, excluding consciousness) with quantum amplitudes and expectation values, but no probabilities, and there is a *conscious world* (what one might call the mental world)
with frequency-type measures or statistical probabilities. Interpreting the unconscious quantum world itself probabilistically is taken to be probabilism, an aesthemamorphic myth.

The axioms of Sensible Quantum Mechanics are the following:

1. **Quantum World Axiom**: The unconscious “quantum world” $Q$ is completely described by an appropriate algebra of operators and by a suitable state $\sigma$ (a positive linear functional of the operators) giving the expectation value $\langle A \rangle \equiv \sigma[A]$ of each operator $A$.

2. **Conscious World Axiom**: The “conscious world” $M$, the set of all conscious perceptions, has a fundamental measure $\mu(S)$ for each subset $S$ of $M$.

3. **Quantum-Consciousness Connection**: The measure $\mu(S)$ for each set $S$ of conscious perceptions is given by the expectation value of a corresponding “awareness operator” $B(S)$, a positive-operator-valued (POV) measure, in the state $\sigma$ of the quantum world:

$$\mu(S) = \langle B(S) \rangle \equiv \sigma[B(S)]. \quad (3)$$

If for simplicity we suppose that there is a discrete set of quantum operators and a discrete set of conscious perceptions or observations $O_j$, then each Sensible Quantum Mechanics (SQM) theory $T_i$ has

1. Set of operators $A^{(i)}_j$ and algebra $A^{(i)}_j A^{(i)}_k = \sum_l c^{(i)}_{jk} A^{(i)}_l$

2. Quantum state $\sigma_1$ giving $\langle A^{(i)}_j \rangle = \sigma[A^{(i)}_j]$.

3. Normalized positive operators $B^{(i)}_j$ for observations $O_j$, $\sum_j \sigma[B^{(i)}_j] = 1$.

4. $L_{ij} \equiv P(O_j|T_i) = \sigma_i[B^{(i)}_j] = $ normalized measure of $O_j$ in $T_i$.

Then if one assigns epistemic prior probabilities $p_i$ for $T_i$ and has the observation $O_j$, the epistemic posterior probability for $T_i$ is, by Bayes’ theorem,

$$P_{ij} \equiv P(T_i|O_j) = \frac{p_i \sigma_i[B^{(i)}_j]}{\sum_k p_k \sigma_k[B^{(k)}_j]} \quad (4)$$

The principles of Bayesian meta-theories proposed here and exemplified by Sensible Quantum Mechanics may be related to various other principles that have been advocated:
1. **Copernican Principle:** We are not specially privileged.

2. **Weak Anthropic Principle:** What we observe is conditioned upon our existence as observers.

3. **Principle of Mediocrity:** We are a “typical” civilization [6].

4. **Strong Self-Sampling Assumption (SSSA):** “One should reason as if one’s present observer-moment were a random sample from the set of all observer-moments in its reference class” [7].

5. **Conditional Aesthetic Principle (CAP):** “Unless one has compelling contrary evidence, one should reason as if one’s conscious perception were a random sample from the set of all conscious perceptions” [2, 3, 4, 5].

3 Application to Single-History versus Many-Worlds Quantum Theory

One can apply these Bayesian meta-theory principles in general, and the framework of Sensible Quantum Mechanics in particular, to various issues. For example, in principle (if the quantum state of the universe is suitable) one can make statistical tests to distinguish between single-universe and many-worlds versions of quantum theory [8, 9, 10].

Consider a set of quantum theories giving 99.9% probability for a small universe with \( N_1 = 1 \) civilization seeing \( O_1 \), say with negative cosmological constant \( \Lambda < 0 \), and 0.1% probability for a large universe, \( N_2 = 10^6 \) civilizations seeing \( O_2 \), say with positive cosmological constant \( \Lambda > 0 \). Let \( T_1 \) be a single-history theory with just a small universe, \( T_2 \) be a single-history theory with just a large universe, and \( T_3 \) a many-worlds theory with both a small and a large universe. Say the respective prior probabilities for these three theories are \( p_1, p_2, \) and \( p_3 \), with \( p_1 + p_2 = 0.9 \) and \( p_3 = 0.1 \), so that initially one gives only 10% probability for many-worlds. Since the small universe is supposed to have 999 times the probability of a large universe, for the single-universe theories say \( p_1 = 0.999(p_1 + p_2) = 0.8991 \) and \( p_2 = 0.001(p_1 + p_2) = 0.0099 \).

In \( T_1 \), \( O_1 \) is certain and \( O_2 \) is impossible, so

\[
L_{11} \equiv P(O_1|T_1) = 1, \quad L_{12} \equiv P(O_2|T_1) = 0. \tag{5}
\]

Conversely, in \( T_2 \), \( O_1 \) is impossible and \( O_2 \) is certain, so

\[
L_{21} \equiv P(O_1|T_2) = 0, \quad L_{22} \equiv P(O_2|T_2) = 1. \tag{6}
\]
On the other hand, in $T_3$, observations are made of both a small universe and a large universe, so if we take the probabilities of the observations to be weighted by the number of civilizations making them, we get

\[
L_{31} \equiv P(O_1|T_3) = \frac{N_1(0.999)}{N_1(0.999) + N_2(0.001)} = \frac{0.999}{1000.999} \approx 0.001, \quad (7)
\]

\[
L_{32} \equiv P(O_2|T_3) = \frac{N_1(0.001)}{N_1(0.999) + N_2(0.001)} = \frac{1000}{1000.999} \approx 0.999.
\]

Suppose then we see $O_2$ (large universe, $\Lambda > 0$). Then applying Bayes’ theorem gives the posterior probabilities of the three theories as

\[
P(T_1|O_2) = \frac{p_1 L_{12}}{p_1 L_{12} + p_2 L_{22} + p_3 L_{32}} = 0, \quad (8)
\]

\[
P(T_2|O_2) = \frac{p_2 L_{22}}{p_1 L_{12} + p_2 L_{22} + p_3 L_{32}} \approx 0.009,
\]

\[
P(T_3|O_2) = \frac{p_3 L_{32}}{p_1 L_{12} + p_2 L_{22} + p_3 L_{32}} \approx 0.991.
\]

Thus, in this hypothetical case, even though initially one gave the many-worlds theory only a 10% prior probability of being true, after the observation one would then give it more than 99% posterior probability of being true. Therefore, in principle one can gain observational evidence of whether or not the many-worlds version of quantum theory is correct; it is not just an equivalent interpretation of a single quantum theory.

4 Application to Fake Universes

Another application is to fake universes. Theories with posthuman civilizations seem in danger of producing too many fake universes [11]. Taking substrate-independence of consciousness as given, Nick Bostrom argues, “... at least one of the following propositions is true:

1. the humans species is very likely to go extinct before reaching a ‘posthuman’ stage;

2. any posthuman civilization is extremely unlikely to run a significant number of simulations of their evolutionary history (or variations thereof);

3. we are almost certainly living in a computer simulation.”

Paul Davies [12] draws the following conclusion from this argument: “For every original world, there will be a stupendous number of available virtual worlds—some of which would even include machines simulating virtual worlds
of their own, and so on ad infinitum.” John Barrow [13] makes the further point, “So we suggest that, if we live in a simulated reality, we should expect occasional sudden glitches, small drifts in the supposed constants and laws of nature over time, and a dawning realization that the flaws of nature are as important as the laws of nature for our understanding of true reality.” If much of posthuman computer simulation is done by the analogue of today’s teenagers, I myself would expect even more chaos in simulations.

Since we have not observed these postulated sudden glitches, drifts, and chaos, we might seek explanations of why they are not seen, incantations to ward off fake universes. Bostrom himself [11] noted that humans may go extinct before becoming posthuman, or that posthumans may be unlikely to run simulations. But Davies [12] is arguing that these explanations would not ward off fake universes if there is a multiverse, which he takes as a reductio ad absurdum suggesting no multiverse.

In my mind, the weakest assumption leading to fake universes is the assumption [11] of the substrate-independence of consciousness. If that is not correct, then it could well be that most simulated beings simply are not conscious (and so, as conscious beings, we are not likely to be simulated). One might analyze this question within the framework of Sensible Quantum Mechanics, which postulates that there is a precise positive operator $B_j$ for each observation or conscious perception $O_j$. Substrate-independence seems vague to me but might be taken to mean that $B_j$ is invariant under some set of transformations (perhaps unitary), such as the assumption that $B_j = \hat{B}_j = UB_j\tilde{U}$ for some set of $(U, \tilde{U})$ pairs. But why should this be true? It seems highly implausible to me.

I am reminded of the South Pacific cargo cults, which arose out of observations during World War II that after airfields and conning towers were built on their islands, aircraft landed with cargo. Thinking that the airfields and conning towers were the sufficient conditions for such cargo to arrive, they themselves built other airfields and conning towers, but the expected cargo did not arrive. It seems to me that we are at a similar primitive stage concerning what conditions are sufficient for consciousness (e.g., what the operators $B_j$ are in Sensible Quantum Mechanics), so guesses that they are substrate independent are very likely to be quite wrong.

5 Application to Boltzmann Brains

Another application is to Boltzmann brains. Theories in which spacetime can last too long seem in danger of producing too many Boltzmann brains
(BBs) with mostly disordered observations, which would make our ordered observations highly atypical [14] [15] [16].

The germ of the idea goes back to Boltzmann [17], who said that his “old assistant” Dr. Schuetz had suggested that our observed universe might be a giant thermal fluctuation. Although this would be extremely improbable for any particular large region of the universe, it would certainly occur somewhere if the universe were large enough.

However, more recently it has been noticed [18] [19] that it would be much less improbable for a particular region of the universe to have just a small fluctuation give our observations, rather than the entire observable region of the universe. For example, one might postulate that a human brain arose from a thermal fluctuation in a state in which it had the same conscious awareness as if it had been making observations of a large region of the universe, even if the large region were actually not at all what the conscious awareness thought it was. (E.g., the conscious perception of the brain might be that observations had been made of distant stars and galaxies, whereas actually the surrounding universe might be empty, without any stars and galaxies, but just having the brain in the same state it would have been if there had been stars and galaxies it had observed.)

For a brain of the rough mass of a human brain of one kilogram to arise from a thermal fluctuation in empty deSitter space at its Gibbons-Hawking [20] temperature $T_{dS}$, the expected number per 4-volume (3-volume of space multiplied by the time interval in spacetime) for such long-lasting brains or ‘long brains’ (lbs) would be

$$N_{lb} \sim e^{-(1 \text{ kg})c^2/T_{dS}} \sim e^{-10^{69}}.$$  (9)

This is very tiny but would apparently be important if the universe lasted long enough to make the total 4-volume large in comparison with $e^{10^{69}}$ times the 4-volume of the region of ordinary observers (OOs).

I realized [14] [15] [16] that the rate would be relatively much larger if the brains were not required to come into long-lasting existence by a thermal fluctuation but were just required to exist momentarily as vacuum fluctuations (‘brief brains’ or bbs). Then if the brain were in the right state or configuration, it could have a brief conscious perception and then disappear into the vacuum again. The minimum requirement presumably would be roughly that the matter of the brain be separated from the corresponding amount of antimatter that would appear during the virtual loops of the Feynman diagrams of the vacuum fluctuation.
For a one-kilogram human brain to become separated by its size of say 30 centimeters from the antimatter would require an action of \((1 \text{ kg})c(0.3 \text{ m})/\hbar \sim 10^{42}\), so the expected number of brief brains per 4-volume would be of the rough order of

\[
N_{bb} \sim e^{-(1 \text{ kg})c(0.3 \text{ m})/\hbar} \sim e^{-10^{42}}.
\] (10)

Although this again is extremely tiny, so that the expected number of these vacuum fluctuation Boltzmann brains or brief brains (bb BBs) would be much less than unity over the whole past history of the part of the universe we can now observe (the ‘observable universe’), it would dominate over ordinary observers if the universe lasted long enough to make the total 4-volume much larger than \(e^{10^{42}}\) times the 4-volume of the region of ordinary observers, which would apparently be the case if the universe expanded forever.

If some theory predicted that Boltzmann brains greatly dominated over ordinary observers, we would expect that in that theory we would most likely be BBs rather than OOs. Only a very tiny fraction of BBs would give consciousness (though say still much larger than the number of OOs), but since we must be conscious to observe anything, this condition is a necessary selection effect, so that if such conscious BBs and/or OOs exist, it would not be at all improbable that we are a conscious BB or OO (and most likely a BB if there are far more conscious experiences produced by them, say in a universe that lasts much longer and grows much bigger than the region where OOs can exist).

However, once we include the necessary selection effect that we are conscious, the conditional probabilities for the various possible natures of the conscious perceptions should be given by the theory. If BBs enormously dominate over OOs, we should expect that we are BBs rather than OOs (or rather you should, since then most probably I am just a figment of your imagination). But only a very tiny fraction of BB conscious perceptions would be expected to be so ordered as yours generally are, with coherent visual images and memories, so the fact that yours are highly ordered counts as strong statistical evidence against any theory that implies that almost all conscious perceptions are produced by BBs (since they would produce mostly disordered observations).

If one includes more details of the order that you observe, then the likelihood that your observation comes from a theory in which BBs dominate is even lower. For example, even among the tiny fraction of BB conscious perceptions that are ordered, only a tiny fraction would give ordered observations of, say, galaxy-galaxy correlations. And of these, only a tiny fraction would
give a galaxy-galaxy correlation similar to what you observe or may be aware of from what you think are the observations of others. So if you put in all the detail of the order that you observe or are aware of, it would be very unlikely that it is a conscious perception produced in a theory in which Boltzmann brains greatly dominate.

Although the next step would be going beyond what could be observationally checked, one might note that even among the extremely tiny fraction of BB conscious perceptions that included all the details of the order that you perceive, only a very tiny fraction of these would be non-illusory, say of actual galaxies, since there would be far more BBs in the entire huge spacetime to have brains in just the right states to have illusory perceptions that they have observed galaxies with all the correlations that you observe or are aware of, than for all the ‘observed’ galaxies actually to exist.

In conclusion, theories in which Boltzmann brains greatly dominate over ordinary observers would make your or my observations highly atypical. Some might argue [1] that this atypicality does not imply a correspondingly small likelihood for these theories, but I would respond [2] that it should.

Let me give some numerical estimates for the conditions that Boltzmann brains might dominate ordinary observers in our universe. Basically, a sufficient condition would seem to be that the expectation value of the total 4-volume of our comoving region of the universe is infinite when one includes the future.

After the period of radiation domination ended when the linear size of a comoving region of our universe was thousands of times smaller than today, our observed comoving region (that given by fixed markers such as galaxies that move apart with the expansion of the universe) is apparently dominated by a cosmological constant \( \Lambda \) and by low-velocity massive particles with negligible pressure (called ‘dust’ in cosmology), a cold-dark-matter-\( \Lambda \) model or CDM\( \Lambda \) model. Its spacetime geometry is apparently well described by the \( k = 0 \) (spatially flat) Friedmann-Robertson-Walker metric with unit-jerk \( (J \equiv a^2(d^3a/dt^3)/(da/dt)^3 = 1, \) where \( a(t) \) is the linear size of a fixed comoving region as a function of the time \( t)\):

\[
   ds^2 = T^2[-d\tau^2 + (\sinh^{4/3}\tau)(dr^2 + r^2d\theta^2 + r^2\sin^2\theta d\phi^2)].
\]  

(11)

The Hubble Space Telescope key project [21] gives that the present Hubble constant of our universe, today’s value of \( H \equiv d\ln a/dt, \) is \( H_0 = 72 \pm 8 \) km/s/Mpc. From the third-year results of the Wilkinson Microwave Anisotropy Probe (WMAP), the fraction of the critical energy density given by the cosmological constant is \( \Omega_\Lambda = 0.72 \pm 0.04. \) Putting these numbers together [14] [16]
gives that the asymptotic value of the Hubble expansion rate in the distant future is

\[ H_\Lambda = \sqrt{\Lambda/3} = H_0\sqrt{\Omega_\Lambda} \approx (16 \pm 2 \text{ Gyr})^{-1}, \]  
(12)

the value of the constant parameter \( T \) in the metric above is

\[ T = (2/3)H_\Lambda^{-1} = 11 \pm 1.5 \text{ Gyr}, \]  
(13)

the present value of the dimensionless time coordinate \( \tau \) in the metric above is

\[ \tau_0 = \tanh^{-1}\sqrt{\Omega_\Lambda} \approx 1.25 \pm 0.09, \]  
(14)

and the present value of the Hubble constant, \( H_0 \), multiplied by the present value of the age, \( t_0 \), or the present value of \( d\ln a/d\ln t \), is

\[ H_0t_0 = \frac{2}{3} \frac{\tanh^{-1}\sqrt{\Omega_\Lambda}}{\sqrt{\Omega_\Lambda}} \approx 0.99 \pm 0.04. \]  
(15)

It is interesting that this last value is consistent with unity, up to a fraction of the current observational uncertainties. This means that when one plots the linear size \( a \) versus the time \( t \) since the beginning in this model (applicable long after very early inflation, and also after radiation domination ended), the \( a(t) \) curve bends downward during the first part of the history (deceleration, when dark matter dominated and made gravity attractive) and then bends upward during the latter part of the past history (acceleration, when the cosmological constant or dark energy dominated and made gravity repulsive on cosmological scales) in just such a way that if one draws a straight line tangent to the \( a(t) \) curve at the present time \( t_0 \), it will have slope \( da/dt \) that is very nearly the same as \( a/t \) and hence will very nearly go through the origin. To put it another way, not counting the very early inflationary period, the value of linear size over age, \( a/t \), is, within the current observational uncertainties, minimized at the present time. This coincidence, along with the observed spatial flatness, plus the fact that the current best estimate \[22\] of the age 13.7 Gyr (Gigayears or billions of years) has the same first three digits as the reciprocal of the fine structure constant, \( 1/\alpha \approx 137.036 \), allows one to write the metric and parameters above in an easy-to-remember form that I might call the mnemonic universe: CDMA \( k = 0 \) FRW \( t_0 = H_0^{-1} = 10^8 \text{ yr}/\alpha \).

If this expanding universe lasts forever, then for any fixed comoving volume (e.g., the physically expanding volume occupied by some fixed set of galaxies and whatever massive particles they may eventually decay into, say electrons and positrons) that presumably contains only a finite number of ordinary observers (say if they cannot exist after the stars burn out in a finite time), one
will have an infinite amount of 4-volume in the infinite future, and hence apparently an infinite number of Boltzmann brains, infinitely dominating over the presumably finite number of ordinary observers. One might however postulate that the universe will not expand forever but perhaps decay to some entirely different configuration obeying quite different effective laws of physics (say not giving any conscious brains at all) by the quantum formation of a bubble that then expands at the speed of light and destroys all that it engulfs. If the bubble nucleation rate per 4-volume is \( A \) (for ‘annihilation,’ which is what the bubble would do to the present form and laws of physics of the universe), then the expectation value of the total 4-volume per fixed comoving 3-volume would be finite only if the bubble formation rate is greater than some calculable minimum \([14, 16]\):

\[
A > A_{\text{min}} = \frac{9}{4\pi} \frac{H_0^4}{\Lambda^4} \approx (18 \pm 2 \text{ Gyr})^{-4} \approx e^{-563},
\]

where the last number is in Planck units, setting \( \hbar = c = G = 1 \).

For a given value of \( A \), the survival probability of the CDM\( \Lambda k = 0 \) FRW model above is

\[
P(t) = \exp \left[ -\frac{16}{27} \frac{A}{A_{\text{min}}} \int_0^{\frac{2}{9} H_0 t} dx \sinh^2 x \left( \int_x^{\frac{2}{9} H_0 t} \frac{dy}{\sinh^{2/3} y} \right)^3 \right].
\]

Given that we have lasted until today, the probability per year for being annihilated by a bubble that has formed just outside our past light cone (and hence which will engulf us within the coming year, though we cannot see any signal of its coming since it would be coming at essentially the speed of light) would be greater than one part in one hundred billion. With the present earth population of nearly 7 billion, this would give an minimal expected death rate of about 7 persons per century. (Of course, it could not be 7 persons in one century, but all 7 billion with a probability of about one in a billion per century.) It also gives an upper limit on the present half-life of our universe of 19 Gyr \([14]\).

Since we do not see that our observations are so disordered as would be statistically predicted if Boltzmann brains greatly dominated over ordinary observers, we might seek an explanation of why they apparently do not dominate, incantations to ward off Boltzmann brains:

1. The universe may be decaying classically if the quintessence potential slowly slides negative, so that the universe rolls into oblivion \([23]\).

2. The universe may be decaying quantum mechanically with \( e^{-563} \lesssim A \lesssim e^{-556} \), though this seems to require unnatural fine tuning \([14, 15, 16]\).
3. Observers might conceivably fill the entire universe and be too large to form by vacuum fluctuations \[14, 15, 16\].

4. The local view restricts the 3-volume to the causal patch \[24\].

5. Use a regularization effectively cutting off before the Boltzmann brains \[25\].

6. Boltzmann brains should be lumped with bubble formation \[26\].

7. Holographic cosmology gives a time-dependent Hamiltonian \[27\].

8. ‘Constants’ of physics change so that the rate per 4-volume of Boltzmann brains asymptotically decays to zero \[28\].

9. Restrict to only certain group-averaged quantum states \[29\].

10. Quantum field theory may not apply to brains \[14, 16\].

11. We may not be typical \[1\].

Since an astronomical decay rate is suggested by one way of regularizing Boltzmann brains, and since it is not completely ruled out, perhaps we should take it seriously as one possibility (though not the only one). So let us see what are implications of the possible astronomical decay rate.

If ordinary observers could last until engulfed by a bubble:

1. They could not see it coming and so would not dread it.

2. They would be destroyed so fast they would feel no pain.

3. There would be no grieving survivors left behind.

So it would be the most humanely possible execution.

Furthermore, the universe will always persist in some decreasing fraction or measure of Everett worlds. Thus one could never absolutely rule out a decaying universe by observations at any finite time, though at sufficiently late times observations would be strong statistical evidence against the astronomical decay rate.

The main point of my discussing this scenario is not to advocate a particular solution to the Boltzmann brain problem, but rather to stimulate more research on the huge scientific mystery of the measure for the string/M landscape \[30, 31\] or other multiverse theory \[32\].
6  Application to Biological Evolution

Sensible Quantum Mechanics suggests we are effectively selected randomly by our measure of consciousness, like winners in a cosmic jackpot [33]. No further selection would be needed within a particular SQM theory.

This does not explain which SQM theory is correct. One might suppose it was chosen by a highly lawful and yet benevolent God (perhaps ultimately simple [34], say the greatest possible being, contra Dawkins’ idea that God is complex [35]), who wanted to create understanding conscious beings in His image within a highly ordered and elegant multiverse.

Within Darwinian evolution on earth, our ancestors would not just be random life but conditionalized by being our ancestors. One or more correlated steps might be highly improbable on a per-planet basis [36] (say \( P \sim 10^{-n} \) with \( n \gg 24 \) so that the probability would be very low for any others within the observable universe of probably not more than \( 10^{24} \) planets). Only steps off our ancestral line can be argued to be probable to occur on a random planet in which the steps up to that point have occurred. It would be interesting to see what features of complexity and intelligence developed off our ancestral line (e.g., to octopi from our last common ancestor), and what features have developed only within our ancestral line. Some of the latter features could be so rare that they have not occurred anywhere else within the observable universe (the part we can see), even though the entire universe may be so vast that all of these features have occurred many times very much further away than we can possibly see.

7  Conclusions

1. Scientific theories need to be testable by observations.

2. Multiverse theories can in principle be testable if they give probabilities for observations that depend upon the theory.

3. Sensible Quantum Mechanics (SQM) gives probabilities that are expectation values of positive operators associated with observations or conscious perceptions, and in principle they can be tested observationally.

4. One can test between single-history and many-worlds theories.

5. Fake universe and Boltzmann brains are threats to certain multiverse (and single-universe) theories.
6. Sensible Quantum Mechanics suggests that fake universes may not be a threat, since there is no compelling reason to believe in the substrate independence of consciousness.

7. There are many suggested solutions for Boltzmann brains, but it just is not clear what the correct one is.

8. No further life principle is needed within a Sensible Quantum Mechanics theory, but which Sensible Quantum Mechanics theory is correct needs explaining.

9. From the view of foresight, our biological ancestors may be highly improbable, post-selected by our existence as beings with a high measure of conscious perceptions.

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