Island Cosmology

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\textbf{Summary.} If the observed dark energy is a cosmological constant, the canonical state of the universe is de Sitter spacetime. In such a spacetime, quantum fluctuations that violate the null energy condition will create islands of matter. If the fluctuation is sufficiently large, the island may resemble our observable universe. Phenomenological approaches to calculating density fluctuations yield a scale invariant spectrum with suitable amplitude. With time, the island of matter that is our observable universe, dilutes and re-enters the cosmological constant sea, but other islands will emerge in the future, leading to an eternal universe.

\section{1 Introduction}

Current observations indicate a bleak future for the universe. The expansion of the universe will accelerate and, if the dark energy is a cosmological constant, all the matter will dilute away, eventually leaving behind empty de Sitter space, the canonical state of the universe.

The classical picture of an empty de Sitter spacetime is modified when quantum field theory effects are taken into account since inevitable quantum fluctuations can speed up or slow down the rate of expansion. There has also been work to investigate whether quantum field theory actually causes instabilities in de Sitter space \cite{4, 5}. Quantum field theoretic fluctuations that violate the null energy condition (NEC) on super-horizon scales can lead to cosmological super-acceleration, producing a super-horizon patch of matter that then evolves as a Friedmann-Robertson-Walker universe embedded within the de Sitter spacetime.

Island cosmology is based on the idea that our observable universe may have originated from an NEC violating quantum fluctuation in the cosmological constant sea. There are a number of attractive features of such an hypothesis. For example, spacetime is eternal, there need not be any singularities, there are observable islands to the future as there are in the past, and the model does not require new physics or unobserved ingredients. The real test of the model is in how successfully it confronts observations and the crucial signatures to study are the spectrum of predicted density and gravitational wave fluctuations.
We now summarize the main features of island cosmology, and discuss the points in detail in the following sections.

Let us begin with a broad overview of Island Cosmology, describing each of its different stages.

![Diagram of Hubble length scale behavior](image)

**Fig. 1.** Sketch of the behavior of the Hubble length scale in inflationary cosmology (left) with respect to cosmic time, $t$, and in island cosmology (right) with respect to conformal time, $\eta$, (which is defined in terms of the scale factor $a(t)$ as $d\eta = a(t)dt$). $H_{\text{inf}}^{-1}$, $H_{\text{FRW}}^{-1}$, and $H_{\Lambda}^{-1}$ denote the Hubble lengths during an inflationary, Friedman-Robertson-Walker and cosmological constant dominated evolution respectively. The evolution of fluctuation modes is also shown in the two models. In inflationary models, early exponential growth is driven by an inflaton field, while in island cosmology it is driven by the presently observed dark energy, assumed to be a cosmological constant. As the cosmological constant is very small, the Hubble length scale is very large – of order the present horizon size. The exponential expansion in island cosmology ends in some horizon volume not due to the decay of the vacuum energy as in inflationary scenarios but due to a quantum fluctuation in the time interval $(\eta_1, \eta_2)$ that violates the Null Energy Condition (NEC). The NEC violating quantum fluctuation causes the Hubble length scale to decrease. After the fluctuation is over, the universe enters radiation dominated FRW expansion, and the Hubble length scale grows with time. The physical wavelength of a quantum fluctuation mode starts out less than $H_{\Lambda}^{-1}$ at some early time $\eta_i$. The mode exits the cosmological horizon during the NEC violating fluctuation ($\eta_{\mu}$) and then re-enters the horizon at some later epoch $\eta_e$ during the FRW epoch.

1. **The $\Lambda$-sea:** Current observations indicate that the Universe is accelerating, with the acceleration driven by some form of Dark Energy [6]. The simplest explanation for a dark energy candidate, which is consistent with observations, is the cosmological constant, $\Lambda$. We take such an expanding universe, inflating with the observed value of the cosmological constant, to be the starting point of our model. In other words, Island Cosmology begins with an expanding de Sitter spacetime with a horizon
size comparable to our present horizon $H_0^{-1}$. We call this spacetime the $\Lambda$-sea.

2. **The Upheaval:** A quantum fluctuation of some field (e.g., scalar field, photon) in a horizon-size volume (which we call an $I$-region) in the $\Lambda$-sea drives the Hubble constant to a large value within this volume. We call this fluctuation the “upheaval”. As a result of the upheaval the Hubble scale in the $I$-region decreases, even though the universe continues to expand. A simple application of the Friedmann equation shows that this can only occur when the null energy condition (NEC) is violated, that is

$$N_{\mu}N_\nu T^{\mu\nu} \geq 0$$  

(1)

where $N$ stands for a null vector, and $T^{\mu\nu}$ represents the energy momentum tensor. As we discuss later, it has been demonstrated Refs. [7–9], that quantum field theoretic fluctuations allow for this possibility.

3. **The Island Universe:** After the upheaval, the Hubble constant within the $I$-region is large, and the $I$-region gets filled with classical radiation, as the NEC-violating field decays into relativistic particles. Thereafter, the $I$-region evolves as a radiation-dominated FRW Universe, and eventually forms our observed Universe. We call a Universe created in this manner an **Island Universe**.

4. **The $\Lambda$-sea, again:** With further evolution, the Island Universe dilutes, the $I$-region is again dominated by the cosmological constant and we are once again left with only the $\Lambda$-sea. Clearly, Island Cosmology is cyclic and the above process can be infinitely repeated.

Island Cosmology does include elements of earlier work such as eternal inflation models, steady state models and ekpyrotic models. While eternal inflation models [10, 11], especially Garriga and Vilenkin’s “recycling universe” [12], (see also the discussion in [13]) use NEC violating quantum fluctuations in the inflaton field to drive the Hubble length scale to smaller values, in Island cosmology, these quantum fluctuations can occur in *any* quantum field and have to be large. In both inflationary cosmology and our case, the quantum fluctuation needs to violate the NEC. Furthermore, in both cases the back-reaction of the fluctuation is assumed to lead to a faster rate of cosmological expansion. In Steady State Cosmology [14, 15], matter is sporadically produced by “minibangs” in a hypothetical C-field. The explosive events in Island Cosmology, on the other hand, are quantum field theoretic in origin and seed the matter content of an entire Universe. The decreasing Hubble scale is also a feature of the ekpyrotic cosmological model [16]. However, in that model, the motivation for the decrease lies in extra-dimensional brane-world physics and results in a period of contraction of our three dimensional universe. Island Cosmology does not involve any brane-world physics, and has no contracting phase, as the Universe continues to expand even while the Hubble scale drops.
2 NEC violations in de Sitter space

In de Sitter spacetime, as well as any other spacetime, there are fluctuations of the energy-momentum tensor, $T_{\mu\nu}$, of quantum fields. This is simply a consequence of the fact that the vacuum, $|0\rangle$, is an eigenstate of the Hamiltonian but not of the Hamiltonian density or the energy-momentum density operator, $\hat{T}_{\mu\nu}$. In short-hand notation:

$$T_{\mu\nu}|0\rangle = \sum [(\ldots) a_l^\dagger a_k^\dagger \ldots a_l^\dagger a_k^\dagger |0\rangle = \sum [(\ldots)|0\rangle + (\ldots)|2; k, l\rangle ] \tag{2}$$

where, the ellipses within parenthesis denote various combinations of mode functions and their derivatives; $a_k^\dagger, a_l$ are creation and annihilation operators and $|2; k, l\rangle$ is a two particle state. The final expression is not proportional to $|0\rangle$, implying that the vacuum is not an eigenstate of $\hat{T}_{\mu\nu}$ and there will be fluctuations of the energy-momentum tensor in de Sitter space.

In de Sitter spacetime, the quantum vacuum state needs to be chosen. If we require that on short distance scales the quantum fields should behave as they do in Minkowski spacetime, then the vacuum state is known as the Bunch-Davies vacuum [17]. It has been shown [7–9] that quantum field theory of a light scalar field in the Bunch-Davies vacuum in de Sitter space leads to violations of the NEC. We now briefly summarize the general arguments behind this conclusion.

The first step is to construct a “smeared NEC operator”

$$\hat{O}_W^{\text{ren}} \equiv \int d^4x \sqrt{-g} W (x; R, T) N^\mu N^\nu \hat{T}_{\mu\nu}^{\text{ren}} \tag{3}$$

where $W (x; R, T)$ is a smearing function on a length scale $R$ and time scale $T$. The vector $N^\mu$ is chosen to be null, and the superscript $\text{ren}$ denotes that the operator has been suitably renormalized. As shown in [7] the smeared operator will not be proportional to the vacuum state either, and will fluctuate. The root-mean-squared (rms) scale of the fluctuations, $\hat{O}_{\text{rms}}^2$ can be estimated on dimensional grounds:

$$\hat{O}_{\text{rms}}^2 \equiv \langle 0 | (\hat{O}_W^{\text{ren}})^2 |0\rangle \sim H_A^8 \tag{4}$$

in the special case when $R = T = H_A^{-1}$. Since, in de Sitter space, $\langle 0 | \hat{T}_{\mu\nu} |0\rangle \propto g_{\mu\nu}$, we also have:

$$\langle 0 | \hat{O}_W^{\text{ren}} |0\rangle = 0 \tag{5}$$

Therefore the fluctuations of $\hat{O}_W^{\text{ren}}$ are both positive and negative. Assuming a symmetric distribution, we come to the conclusion that quantum fluctuations of a scalar field violate the NEC with 50% probability. Exactly the same arguments can be applied to quantum fluctuations of a massless gauge field such as the photon.
Note that the above calculation does not give us the probability distribution of the violation amplitude, for which we would have to calculate the actual probability distribution for the operator $\hat{O}^{\text{ren}}_{W}$. However, by continuity we can expect that large amplitude NEC violations will also occur with some diminished but non-zero probability.

### 3 Extent and duration of NEC violation

![Penrose diagram](image)

**Fig. 2.** We show a Penrose diagram ($\eta$ vs $r$, where $\eta$ is conformal time and $r$ is the radial coordinate of a null ray) for a classical de Sitter spacetime for conformal time $\eta < \eta_P$, that transitions to a faster expanding classical de Sitter spacetime for $\eta > \eta_Q$. Future null infinity, denoted by $\mathcal{I}^+$, occurs along the horizontal upper edge of the diagram. The inverse Hubble size is shown by the white region. A bundle of ingoing null rays originating at point $a$ is convergent initially but becomes divergent in the superhorizon region at point $b$. This can only occur if the null energy condition violating is violated in the region $\eta \in (\eta_P, \eta_Q)$. In the quantum domain, a classical picture of spacetime may not be valid and this is made explicit by the question marks.

What is the spatial and temporal extent of these NEC-violating fluctuations? Clearly, such fluctuations can occur on all spatial and temporal scales, but based on causality and predictability, we will now argue that only fluctuations of a large (horizon-sized) spatial extent and small temporal duration are relevant to creating islands of matter.
Consider the spacetime diagram of Fig. 2. In this diagram we show an initial de Sitter space that later has a patch in which the space is again de Sitter though with a larger expansion rate. Consequently, the initial Hubble length scale $H_i^{-1}$ is larger than the final Hubble length scale $H_f^{-1}$. It follows, therefore, that there are ingoing null rays that are within the horizon initially but eventually propagate outside the horizon. An example of such a null ray is the line from $a$ to $b$. At point $a$ a bundle of such rays will be converging whereas at point $b$ the bundle will be diverging. It can be demonstrated from the Raychaudhuri equation (subject to a few mild conditions, such as general relativity being valid and spacetime topology being trivial) that the transition from convergence to divergence of a bundle of null rays can only occur if there is a NEC violation somewhere along the null ray (see [18]).

Now if the NEC violation only occurred on a scale smaller than $H_i^{-1}$, one could imagine a null ray that would never enter the NEC violating region and yet go from being converging to diverging (see Fig. 3). This would clearly be inconsistent with the Raychaudhuri equation.

![Fig. 3. A spacetime diagram similar to that in Fig. 2 but one in which the Null Energy Condition (NEC) violation occurs over a sub-horizon region (shaded region in the diagram). Now the null ray bundle from $a$ to $b$ goes from being converging (within the horizon) to diverging (outside the horizon). However, it does not encounter any null energy condition violation along its path, and this is not possible as can be seen from the Raychaudhuri equation. Since the ingoing null rays are convergent as far out as the point $P$, the size of the quantum domain has to extend out to at least the inverse Hubble size of the initial de Sitter space. Therefore the NEC violating patch has to extend beyond the initial horizon.](image-url)
Furthermore, after the energy condition violations are over, the faster expanding region would have to either instantly revert to the ambient expansion rate, or some spacetime feature, such as a singularity, would have to occur to prevent a null ray from entering the faster-expanding region from the slower-expanding region. Additional boundary conditions would have to be imposed on the singularity to restore predictability. An example of such a process can be found in Ref. [19] in connection with topological inflation [20, 21].

Another way of understanding the loss of predictability is the following. Whenever a faster expanding universe is created, it must be connected by a wormhole to the ambient slower expanding region. The wormhole can be kept open if the energy conditions are violated [22]. But, if the wormhole neck is small, as soon as the energy condition violations are over, it must collapse and pinch off into a singularity. Signals from the singularity can propagate into the faster expanding universe destroying predictability. However, if the neck of the wormhole is larger than the horizon size of the ambient universe, the ambient expansion can hold up the wormhole and the neck does not collapse even after the NEC violation is over.

Our argument that NEC violations on scales larger than the horizon are needed to produce a faster expanding universe is consistent with earlier work [23] showing that it is not possible to produce a universe in a laboratory without an initial singularity (also see [24]). Subsequent discussion of this problem in the quantum context [25–27], however, showed that a universe may tunnel from nothing without an initial singularity, just as in quantum cosmology [28, 29]. Such a tunneling event, however, is irrelevant to Island Cosmology, as the newly created universe is causally disconnected from the ambient $\Lambda$-sea. Without an inflaton, the process would therefore produce only a second $\Lambda$-sea.

Based on the above arguments, and on the results of the earlier investigations cited, we conclude that to get a faster expanding region that lasts beyond the duration of the quantum fluctuation and remains predictable, the spatial extent of the NEC violating fluctuation must be larger than $H_i^{-1}$:

$$R > H_i^{-1} \quad (6)$$

where $R$ is the spatial extent of the fluctuation and shows up as the spatial smearing scale in the calculation of $\hat{O}_{\text{rms}}$.

We also argue that the temporal scale of the fluctuation has to be small. This is because, an explicit evaluation [7] shows that $\hat{O}_{\text{rms}}$ is proportional to inverse powers of the temporal smearing scale and diverges as the smearing time scale $T \to 0$. Hence the briefer the fluctuation, the stronger it can be, as we might also expect from an application of the Heisenberg time-energy uncertainty relation. Therefore we take the time scale of the NEC violation to be vanishingly small:

$$T \to 0 \quad (7)$$
4 Likelihood – the role of the observer

Any cosmology that relies on fluctuations or initial conditions must explain why the particular fluctuation or initial condition was chosen. This issue is common to all presently known cosmological models. For example, inflationary cosmology chooses the inflaton in a particular location on the potential as an initial condition (“top of the hill”) and a starting universe that consists of several horizons with homogeneous conditions. In island cosmology too, we need to discuss the likelihood of having NEC violating fluctuations that are large enough to produce habitable islands.

In Sec. 3 we have pointed out that the NEC-violating fluctuations need to have two requirements to be cosmologically relevant - they need to have a superhorizon spatial extent and must be of vanishingly small duration. There is one more requirement that is absolutely crucial - the fluctuations must have the correct amplitude in order to have sufficient energy density to lead to our observed Universe. Clearly, only if the temperature produced is high enough and the end point of the NEC violating fluctuation is a thermal state with all the different forms of matter in thermal equilibrium, further evolution of the island will simply follow the standard big bang cosmology.

Admittedly the three requirements of large spatial extent, small temporal extent and large amplitude make these fluctuations rare. However, since spacetime is eternal in this model, we can wait indefinitely for such a fluctuation to occur. The probability of fluctuations in the $A$-sea that can lead to an inflating cosmology versus those that produce an FRW universe have been considered by several researchers [30, 31]. In particular, Dyson et al. [30] estimate probabilities based on a “causal patch” picture, which assumes that the physics beyond the de Sitter horizon is irrelevant to the physics within, and that the latter should be regarded as the complete physics of the Universe. Based on this picture, the authors of [30] conclude that it is much more probable to directly create a universe like ours than to arrive at our present state via inflation. Albrecht and Sorbo [31] have argued that the conclusion rests crucially on the causal patch picture, and provide a different calculation leading to the conclusion that inflationary cosmology is favored. Both the above calculations assume the existence of fields that are suitable for inflation. However, Island Cosmology does not rely on the hypothesis of the inflaton, and so the comparison of the likelihood of inflation versus no inflation is moot.

The monopole overabundance problem can be resolved in Island Cosmology in a manner similar to that proposed in Ref. [32], by assuming that the temperature required for magnetic monopoles production is higher than that required for matter-generation. If the temperature at the beginning of the FRW phase is below that needed for monopole formation but above the matter-generation temperature then there will be no cosmological magnetic monopole problem.
Another important question is where we are located on the island. Are we close to the edge of the island (“beach”)? In that case we would observe anisotropies in the CMB since in some directions we would see the $\Lambda$-sea while in others we would see inland. However, the island is very large (by a factor $a_0/a_f$, the ratio of the scale factors today and at the end of the NEC violation) compared to our present horizon, $H^{-1}_\Lambda$. If we assume a uniform probability for our location on the island, our distance from the $\Lambda$-sea will be an $O(1)$ fraction of $H^{-1}_\Lambda a_0/a_f$. Since $a_0/a_f$ is of order $T_{mg}/T_0$ – the ratio of the matter-genesis temperature to the present temperature – we are most likely to be sufficiently inland so as not to observe any anisotropy in the CMB.

5 The NEC violating field

Whereas inflationary models crucially rely on the existence of a suitable scalar field (inflaton), we have so far not specified the quantum field that causes the NEC violating fluctuation. We now turn to this issue.

During the NEC-violating fluctuation, the energy density of the universe satisfies $\rho + p < 0$, or in other words, behaves like a phantom field (a field with an equation of state parameter $w < -1$). In addition, in order to be able to compute the spectrum of perturbations arising from this model, we make the assumption that the backreaction is given by the Friedmann equation, which requires that $\rho > 0$. Hence we need a quantum field whose energy density has to be positive, but whose pressure should be sufficiently negative so that the NEC is violated.

First consider a scalar field, $\phi$, with potential $V(\phi)$. The energy density and pressure are:

\[
\hat{\rho} = \frac{1}{2} \dot{\phi}^2 + \frac{1}{2} (\nabla \phi)^2 + V(\phi)
\]
\[
\hat{p} = \frac{1}{2} \dot{\phi}^2 - \frac{1}{6} (\nabla \phi)^2 - V(\phi)
\]

where the hats on $\rho$ and $p$ emphasize that these are quantum operators. Therefore:

\[
\hat{\rho} + \hat{p} = \dot{\phi}^2 + \frac{(\nabla \phi)^2}{3}
\]

The operators $\hat{\rho}$ and $\hat{\rho} + \hat{p}$ are not proportional to each other and fluctuations in one do not have to be correlated with fluctuations of the other. The energy density in a region can be positive while the NEC is violated. Therefore a scalar field, even if $V(\phi) = 0$, can provide suitable NEC violating fluctuations.

Particle physics in the very early stages of the model is described by low energy particle physics that we know so well. At present we do not have any experimental evidence for a scalar field. The only light field that we know of
today is the electromagnetic field. Could the electromagnetic field give rise to a suitable NEC violating fluctuation?  

For the electromagnetic field, the energy density and pressure can be written terms of the electric and magnetic fields $E$ and $B$ respectively as:

$$\hat{\rho} = \frac{1}{2} (E^2 + B^2)$$
$$\hat{p} = \frac{1}{6} (E^2 + B^2) = \frac{1}{3} \hat{\rho}$$

(10)

So now $\hat{\rho}$ and $\hat{p}$ are not independent operators and

$$\hat{\rho} + \hat{p} = \frac{4}{3} \hat{\rho}$$

(11)

From this relationship between the operators, it is clear that the only electromagnetic fluctuation that can violate the NEC also has negative energy density. This means that even though the electromagnetic field can violate the NEC, it does not satisfy the positive energy density condition when it does violate the NEC, and this makes it hard to find the backreaction of the fluctuation on the spacetime metric. It may be possible that the electromagnetic field will still be found to be suitable once we know better how to handle the backreaction problem. Then perhaps we will not need to rely on the classical cosmological equations that require positive energy density.

There is a possible loophole in our discussion of the electromagnetic field. The equation of state $\hat{p} = \hat{\rho}/3$ follows from the conformal invariance of the electromagnetic field $\hat{T}_{\mu\nu} = 0$. However, we know that quantum effects in curved spacetime give rise to a conformal anomaly and the trace $\langle \hat{T}_{\mu\nu} \rangle$ is not precisely zero. So we can expect that the equation of state $\hat{p} = \hat{\rho}/3$ is also anomalous. Whether this anomaly can allow for NEC violations with positive energy density is not clear to us.

Note that it is not necessary for the NEC violation to originate from a fluctuation of a massless or light field. The arguments of Sec. 2 are very general and apply to massive fields as well. Though, for a massive field, $\hat{O}_{\text{rms}}$ will be further suppressed by exponential factors whose exponent depends on powers of $H\Lambda/m$.

6 The perturbation spectrum

One of the most crucial observational tests for any cosmology is the spectral index of perturbations that it generates.

Unlike most models of inflation, computing the perturbation spectrum in Island Universes is extremely difficult, for two reasons. Firstly, one requires an adequate characterization of the back-reaction of the NEC violating quantum fluctuations on the metric. The second complication arises from the fact that
both the background field $\phi$ and its perturbation $\delta\phi$ are quantum operators, unlike the case of inflation, where the background field is the solution to some classical equation of motion.

If the backreaction can still be described by the Friedmann equation, it has been shown that perturbation spectra of fields other than, and not interacting with, the NEC violating field, have a nearly scale-invariant spectrum [3]. Assuming that the NEC-violating field itself behaves as a classical phantom field for the duration of the NEC violation, it has been shown [33] that both the scalar and tensor spectra are scale-invariant (also see [34]). In the latter case, interestingly, the scalar spectrum turns out to have an amplitude of $H_f/m_{Pl}$, (where $H_f$ is the value of the Hubble parameter at the end of the fluctuation, and $m_{Pl}$ is the Planck mass) implying that if the NEC violation ends at the GUT scale, then the amplitude of fluctuations is sufficient to seed structure. A full quantum-mechanical treatment of this problem is necessary.

7 A critical review of Island Cosmology

Finally, we put Island Cosmology in perspective by taking a critical look at the assumptions upon which it is based, and comparing these to the assumptions underpinning other cosmological models.

Our first assumption is that the dark energy is a cosmological constant. This is consistent with observations and moreover is the simplest explanation of the Hubble acceleration. We assume that the cosmological constant provides us with a background de Sitter spacetime that is eternal (For a discussion of the timescale on which the spacetime can remain de Sitter, see Ref. [35]). As de Sitter spacetime also has a contracting phase, the singularity theorems of Ref. [36] are evaded.

The second assumption is the existence of a field in the model responsible for the NEC violation. A scalar field seems to be the likeliest candidate, though an electromagnetic field would have been more satisfactory. However, we have shown (up to the loophole of the conformal anomaly) that the conformal invariance of the electromagnetic field prevents NEC violations with positive energy density. It is possible that with a better understanding of the backreaction of quantum energy-momentum fluctuations on the spacetime, the electromagnetic field might still provide suitable NEC violations.

The NEC violation itself is a clear consequence of quantum field theory and is not an assumption (though one could reasonably question the applicability of quantum field theory on systems with horizons.) There seems to be little doubt that large amplitude NEC violations do occur, though they are far less frequent than the small amplitude violations. The idea that NEC violating fluctuations could have played an important cosmological role is also to be found in the “eternal inflation” scenario [37]. While we may not be able to test the idea of cosmological NEC violating fluctuations, we can
certainly test quantum fluctuations with and without horizons in laboratory experiments [38–41].

The third assumption concerns the spatial extent of the fluctuation. Based on work done on the possibility of creating a universe in a laboratory, topological inflation, and wormholes, we have argued for the conjecture that small scale violations of NEC can only give rise to universes that are affected by signals originating at a singularity. Hence predictability is lost in such universes. Our assumption is that even if we did know how to handle the spacetime singularities affecting these universes, they would turn out to be unsuitable for matter genesis. Without this assumption, we should also be considering such universes as possible homes.

The fourth assumption is that the NEC-violating fluctuation ends in a thermal state. All the different energy components are also assumed to be in thermal equilibrium. We have then assumed that the critical temperature needed for observers to exist is the temperature at which matter-genesis occurs. One could relax this assumption but one would need an adequate characterization of the most likely state to be able to calculate cosmological observables (for instance, the spectrum of density fluctuations).

This brings us to the part of the model where we argue that even if the large amplitude fluctuations are infrequent, they are the only ones that are relevant for observational cosmology. This is quite similar to the arguments given in the context of eternal inflationary cosmology where thermalized regions are relatively rare but these are the only habitable ones. It also occurs in chaotic inflation [42], where closed universes of all sizes and shapes are produced but only a few are large and homogeneous enough to develop into the present universe. So this part of Island Cosmology is no weaker (and harder to quantify) than other cosmological models.

8 Conclusions

To conclude, we have described a new cosmological model, which we call “Island Cosmology”, where large NEC violating quantum fluctuations (“upheavals”) in a cosmological constant filled de Sitter spacetime create islands of matter. In Island Cosmology, spacetime may be non-singular and eternal, and an inflationary stage is not necessary.

Like inflation, the only observational signature of Island Cosmology is the spectrum of density perturbations. Assuming that the spectrum of perturbations in Island Cosmology agrees with observations, the question would arise as to whether it is possible to somehow distinguish Island Cosmology from an inflationary scenario that is also consistent with observations. Unfortunately the answer seems to be that no cosmological observation can distinguish between the scenarios because of the immense adaptability of inflationary models. The only distinguishing feature would have to come from the field theory side since Island Cosmology does not rely on constructing a
suitable potential for a scalar field whereas this seems to be a crucial feature in inflationary models. In fact, if the electromagnetic field is subsequently determined to be capable of providing suitable NEC violations, scalar fields might be dispensed off entirely in Island Cosmology. The converse of this is that if the density fluctuations turn out not to agree with observations, we can dismiss the scenario of our universe being an island in the $\Lambda$-sea, even though quantum field theory predicts the existence of such islands. This would be an interesting conclusion as well.

Island Cosmology is attractive because it is a minimalistic model. It uses currently observed features of the Universe as its ingredients and combines them with well-established results from quantum field theory to account for the Universe that we live in now.

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