

difference from $\mathcal{O}(10^{-5})$ to $\mathcal{O}(1)$ in the observable stage of inflation are ruled out by the large scale isotropy of the observable universe.

At the remainder of this section, we would like to make several additional comments for multi-stream inflation:

The possibility that the bifurcated trajectories never recombine. In this case, one needs to worry about the domain walls, which do not become domain fence during inflation. These domain walls may eventually become domain fence after reheating anyway. Another problem is that the e-folding numbers along different trajectories may differ too much, which produce too much anisotropies in the CMB and the large scale structure. However, similar to the discussion in the case of non-symmetric bifurcation, in this case, the observable effect could become great voids due to a large e-folding number difference. The case without recombination of trajectory also has applications in eternal inflation, as we shall discuss in the next section.

Probabilities for different trajectories. In [4], we considered the simple example that during the bifurcation, the inflaton will run into trajectories A and B with equal probabilities. Actually, this assumption does not need to be satisfied for more general cases. The probability to run into different trajectories can be of the same order of magnitude, or different exponentially. In the latter case, there is a potential barrier in front of one trajectory, which can be leaped over by a large fluctuation of the isocurvature field. A large fluctuation of the isocurvature field is exponentially rare, resulting in exponentially different probabilities for different trajectories. The bifurcation of this kind is typically non-symmetric.

Bifurcation point itself does not result in eternal inflation. As is well known, in single field inflation, if the inflaton releases at a local maxima on a “top of the hill”, a stage of eternal inflation is usually obtained. However, at the bifurcation point, it is not the case. Because although the χ direction releases at a local maxima, the φ direction keeps on rolling at the same time. The inflation direction is a combination of these two directions. So multi-stream inflation can coexist with eternal inflation, but itself is not necessarily eternal.

III. ETERNAL BIFURCATIONS

In multi-stream inflation, the bifurcation effect may either take place at an eternal stage of inflation. In this case, it provides interesting ingredients to eternal inflation. These ingredients include alternative mechanism to produce different bubble universes and local terminations for eternal inflation, as we shall discuss separately.

Multi-stream bubble universes. The most discussed mechanisms to produce bubble universes are tunneling processes, such as Coleman de Luccia instantons [12] and Hawking Moss instantons [13]. In these processes, the tunneling events, which are usually exponentially suppressed, create new bubble universes, while most parts

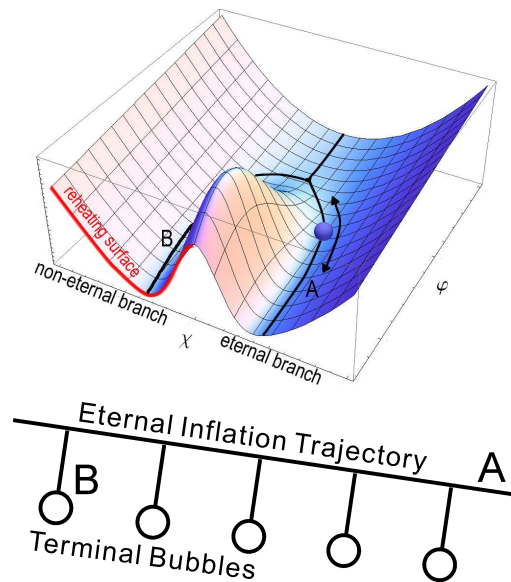


FIG. 4. Cascade creation of bubble universes. In this figure, we assume trajectory A is the eternal inflation trajectory, and trajectory B is the non-eternal inflation trajectory.

of the spatial volume remain in the old bubble universe at the instant of tunneling.

If bifurcations of multi-stream inflation happen during eternal inflation, two kinds of new bubble universes can be created with similar probabilities. In this case, at the instant of bifurcation, both kinds of bubble universes have nearly equal spatial volume. With a change of probabilities, the measures for eternal inflation should be reconsidered for multi-stream type bubble creation mechanism.

If the inflation trajectories recombine after a period of inflation, the different bubble universes will eventually have the same physical laws and constants of nature. On the other hand, if the different inflation trajectories do not recombine, then the different bubble universes created by the bifurcation will have different vacuum expectation values of the scalar fields, resulting to different physical laws or constants of nature. It is interesting to investigate whether the bifurcation effect is more effective than the tunneling effect to populate the string theory landscape.

Note that in multi-stream inflation, it is still possible that different trajectories have exponentially different probabilities, as discussed in the previous section. In this case, multi-stream inflation behaves similar to Hawking Moss instantons during eternal inflation.

Local terminations for eternal inflation. It is possible that during multi-stream inflation, an inflation trajectory bifurcates into one eternal inflation trajectory and one non-eternal inflation trajectory with similar probability. In this case, the inflaton in the eternal inflation trajectory frequently jumps back to the bifurcation point, resulting in a cascade creation of bubble universes, as illustrated in Fig. 4. This cascade creation of bubble universes, if