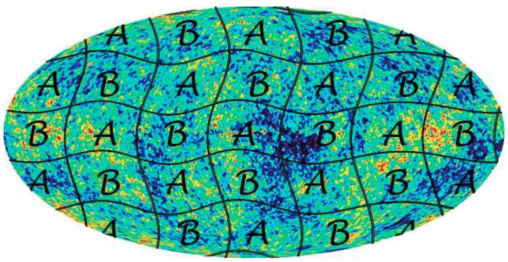

FIG. 3. In multi-stream inflation, the universe breaks up into patches with comoving scale k_1. Each patch experienced inflation either along trajectories A or B. These different patches can be responsible for the asymmetries in the CMB.

CMB, and investigate some other possible observational effects.

To be explicit, we focus on one single bifurcation, as illustrated in Fig. 2. We denote the initial (before bifurcation) inflationary direction by φ, and the initial isocurvature direction by χ. For simplicity, we let $\chi = 0$ before bifurcation. When comoving wave number k_1 exits the horizon, the inflation trajectory bifurcates into A and B. When comoving wave number k_2 exits the horizon, the trajectories recombines into a single trajectory. The universe breaks into of order k_1/k_0 patches (where k_0 denotes the comoving scale of the current observable universe), each patch experienced inflation either along trajectories A or B. The choice of the trajectories is made by the isocurvature perturbation $\delta\chi$ at scale k_1. This picture is illustrated in Fig. 3.

We shall classify the bifurcation into three cases:

Symmetric bifurcation. If the bifurcation is symmetric, in other words, $V(\varphi, \chi) = V(\varphi, -\chi)$, then there are two potentially observable effects, namely, quasi-single field inflation, and a effect from a domain-wall-like objects, which we call domain fences.

As discussed in [4], the discussion of the bifurcation effect becomes simpler when the isocurvature direction has mass of order the Hubble parameter. In this case, except for the bifurcation and recombination points, trajectory A and trajectory B experience quasi-single field inflation respectively. As there are turnings of these trajectories, the analysis in [6] can be applied here. The perturbations, especially non-Gaussianities in the isocurvature directions are projected onto the curvature direction, resulting in a correction to the power spectrum, and potentially large non-Gaussianities. As shown in [6], the amount of non-Gaussianity is of order

$$f_{NL} \sim P_\zeta^{-1/2} \left(\frac{1}{H} \frac{\partial^3 V}{\partial \chi^3} \right) \left(\frac{\dot{\theta}}{H} \right)^3 , \qquad (1)$$

where θ denotes the angle between the true inflation direction and the φ direction.

As shown in Fig. 3, the universe is broken into patches during multi-stream inflation. There are wall-like boundaries between these patches. During inflation, these boundaries are initially domain walls. However, after the recombination of the trajectories, the tensions of these domain walls vanish. We call these objects domain fences. As is well known, domain wall causes disasters in cosmology because of its tension. However, without tension, domain fence does not necessarily cause such disasters. It is interesting to investigate whether there are observational sequences of these domain fences.

Nearly symmetric bifurcation If the bifurcation is nearly symmetric, in other words, $V(\varphi, \chi) \simeq V(\varphi, -\chi)$, but not equal exactly, which can be achieved by a spontaneous breaking and restoring of an approximate symmetry, then besides the quasi-single field effect and the domain fence effect, there will be four more potentially observable effects in multi-stream inflation, namely, the features and asymmetries in CMB, non-Gaussianity at scale k_1 and squeezed non-Gaussianity correlating scale k_1 and scale k with $k_1 < k < k_2$.

The CMB power asymmetries are produced because, as in Fig. 3, patches coming from trajectory A or B can have different power spectra P_ζ^A and P_ζ^B, which are determined by their local potentials. If the scale k_1 is near to the scale of the observational universe k_0, then multi-stream inflation provides an explanation of the hemispherical asymmetry problem [10].

The features in the CMB (here feature denotes extra large perturbation at a single scale k_1) are produced as a result of the e-folding number difference δN between two trajectories. From the δN formalism, the curvature perturbation in the uniform density slice at scale k_1 has an additional contribution

$$\delta\zeta_{k_1} \sim \delta N \equiv |N_A - N_B| . \qquad (2)$$

These features in the CMB are potentially observable in the future precise CMB measurements. As the additional fluctuation $\delta\zeta_{k_1}$ does not obey Gaussian distribution, there will be non-Gaussianity at scale k_1.

Finally, there are also correlations between scale k_1 and scale k with $k_1 < k < k_2$. This is because the additional fluctuation $\delta\zeta_{k_1}$ and the asymmetry at scale k are both controlled by the isocurvature perturbation at scale k_1. Thus the fluctuations at these two scales are correlated. As estimated in [4], this correlation results in a non-Gaussianity of order

$$f_{NL} \sim \frac{\delta\zeta_{k_1}}{\zeta_{k_1}} \frac{P_\zeta^A - P_\zeta^B}{P_\zeta^A} P_\zeta^{-1/2} . \qquad (3)$$

Non-symmetric bifurcation If the bifurcation is not symmetric at all, especially with large e-folding number differences (of order $\mathcal{O}(1)$ or greater) along different trajectories, the anisotropy in the CMB and the large scale structure becomes too large at scale k_1. However, in this case, regions with smaller e-folding number will have exponentially small volume compared with regions with larger e-folding number. Thus the anisotropy can behave in the form of great voids. We shall address this issue in more detail in [11]. Trajectories with e-folding number