Brane collisions and braneworld cosmology

Uchida Gen, Akihiro Ishibashi, and Takahiro Tanaka
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502

Recently, we proposed a new braneworld model GIT in which the collision of a brane universe and a vacuum bubble coming from the extra-dimension is utilized as a trigger of brane big-bang. In this article, mainly reviewing this model, we briefly summarize cosmological braneworld scenarios in which collision of branes plays an important role.

Introduction

Braneworld scenario especially of the Randall-Sundrum type RS have recently attracted much attention. In particular, cosmological models in this scenario have been studied actively BWC,CP. It has been shown that braneworld cosmology seems to be consistent with the 4-dimensional conventional cosmology at least on scales much lower than that corresponding to the brane tension, provided bulk Weyl curvature is sufficiently small. However, it is not clear whether braneworld cosmology can predict any evidences for the existence of extra-dimension(s) which are testable in near future observations. Further, it is still not evident whether braneworld models actually have a great advantage over the conventional ones. Under such a current situation, it is an important direction of research to seek for an alternative scenario in which the existence of extra-dimension(s) plays an essential role.

As one of such attempts, the present authors recently proposed a new cosmological braneworld model GIT in which an inflation occurs on a boundary brane driven by small mismatch between the bulk vacuum energy and the brane tension, and the nucleation of a true vacuum bubble becomes a trigger of the big-bang in the braneworld. One of the distinctive features in our model is that the bubble nucleation occurs in extra-dimension(s). Not only does such a vacuum bubble coming from extra-dimension heat up the brane universe through the colliding process, but also provide simultaneously an anti-de Sitter bulk of the Randall-Sundrum setup, reducing the effective cosmological constant on the brane to zero.

In this article, we shall briefly summarize a colliding brane cosmology. We first give a brief review of colliding brane models so far proposed in the next section. Then, in section sect:Bbbbbbb, we illustrate our brane big-bang model proposed in Ref. GIT. In section Sect:Discussion), we discuss problems in our model, some of which may be common in any types of colliding brane models.

Colliding brane cosmology Sect:brane-collision

Recently there have appeared several interesting works in which collision of branes is actively used. Among them, one of the most fascinating and ambitious ones is the ekpyrotic model KOST, which is proposed aiming at solving major cosmological problems without the use of inflation, based on Horava-Witten theory HW. In this model, a visible brane which is initially Minkowskian turns to big-bang universe after the collision with a bulk brane moving along the 5th-dimension from a hidden brane. A severe criticism KKL to it and a number of calculations of density fluctuations with the controversial claim have also been made ControversialKOST.

Also in the context of Horava-Witten theory, an intriguing possibility that the collision of a visible brane and a bulk moving brane generates the baryon asymmetry on a visible brane universe has been proposed very recently by Bastero-Gil et.al BGCGLP.

Within the context of the Randall-Sundrum scenario, some models to consider bubble nucleation in the bulk have been discussed in several different contexts bubbenucleation. For example, an idea to realize the Randall-Sundrum setup by a collision of bubbles was discussed by Gorsky and Selivanov Gorsky, where the bubbles nucleate through the Schwinger process in some external field.

Bucher Bucher proposed an interesting model in which anti-de Sitter bubbles appear as a result of a false vacuum decay CD and a collision of the two nucleated bubbles create a hot big bang universe, giving a possible origin of a homogeneous and isotropic bulk and brane geometry. Density perturbations in this model have also been calculated JB,GT2 to show that the scale-invariant spectrum does not easily arise. But the result does not immediately exclude the possibility of this model because the amplitude due to the effect of the bubble wall fluctuations tends to be very tiny. Our model we review in the next section has several similarities with this colliding bubble model.
It should be commented that in general relativity, brane (shell) collisions have been discussed in a number of literatures collision. The formalism for treating collision of gravitating shells developed in conventional general relativistic context has been extended to more general cases with an eye for applications in braneworld cosmology LMW. However, concerning perturbations of colliding brane models, as far as the present authors know, such a formalism taking self-gravity of colliding branes into account has not been developed yet. Most of perturbation calculations in colliding brane models have been made by ignoring self-gravity of colliding branes, or after reducing the system in question to effective 4-dimensional theories with a scalar field which mimics fluctuation of a moving brane.

Brane big-bang brought by bulk bubble sect:Bbbbbbb

Now we shall illustrate our idea GIT. In our model, 5-dimensional bulk spacetime is supposed to nucleates in a false vacuum phase with a single positive tension brane at the fixed point of $Z_2$-symmetry. The false vacuum bulk can be locally Minkowski or de Sitter space. The pre-existing brane is in an inflationary phase because of the mismatch between the bulk vacuum energy and the brane tension. This inflationary phase would last forever if there were no mechanism to terminate it. However, since the bulk is initially in a false vacuum state, a true vacuum anti de Sitter-bubble (AdS-bubble) spontaneously nucleates in the bulk as a result of the false vacuum decay via quantum tunneling CD. This AdS-bubble expands in the false vacuum bulk. If the transition occurs with the highest symmetry, the nucleated bubble has the common center which respects the symmetry of the bulk-brane system. However, even if the transition with the highest symmetry is the most probable process as discussed in Ref. CGM, quantum fluctuations lead to displacement of the position of the nucleation from the center of the symmetry. Then, because the surface of the AdS-bubble expands just like a de Sitter space, the bubble eventually hits the inflationary brane universe. The point is that the intersection of the brane and the bubble is spacelike. Thus, when the bubble hits the brane, the energy of the bubble wall can be converted into radiation on the brane unless it dissipates into the bulk. Furthermore, the effective cosmological constant on the brane is reduced with the true vacuum energy chosen to be the negative value which balances the tension of the brane. As a result, the inflation comes to an end, and the brane can be thermalized through this colliding process. It is worth noting that the brane is instantaneously heated up at the colliding surface beyond the horizon scale of the brane. Although such a type of thermalization appears a causality violation from the viewpoint of the observers on the brane, it is a natural consequence of the bubble nucleation in the bulk (outside the brane). We call this collision hypersurface a ”big-bang surface.” If the brane inflation lasts long enough before the collision, the big-bang surface can become homogeneous and isotropic. Then, in the future of the big-bang surface, the brane evolves as a radiation dominated Friedmann-Lemaître-Robertson-Walker (FLRW) universe.

After the collision, the bulk around the brane becomes anti-de Sitter spacetime and the gravity is effectively localized on the brane by the Randall-Sundrum mechanism. Since the true vacuum energy is lower than that in the false vacuum, this model allows a creation of anti-de Sitter bulk from de Sitter or Minkowski-bulk CD. The whole story is summarized in Fig. fig:geom.

figure = 9.5 cm geom.eps

The conformal diagram shows the brane big-bang scenario. The dotted line hemisphere represents the instanton of the system. A true vacuum AdS-bubble is nucleated and expands in the false vacuum bulk bounded by an inflating de Sitter brane. The expanding AdS-bubble eventually collides with a portion of the de Sitter brane. The case that the separation $\Delta$ of the two centers is spacelike is illustrated. In this case, the intersection, i.e., the big-bang surface, has a hyperbolic geometry $H^3$ and an open FLRW brane universe is realized after the brane big-bang. This geometry is glued along the boundary surfaces, except $\mathcal{I}_{AdS}$ and $\mathcal{I}_{Min}$, onto a copy of itself with $Z_2$-symmetry being satisfied. fig:geom