P2IO report on my research activity since my arrival

Shuntaro Mizuno (Postdoc, Paris 11 University, LPT , Cosmology group)

1. Project goals

At present, superstring theory is widely regarded as the most promising candidate of a gravitational theory which is more fundamental and takes over GR at high energies. Therefore, many interesting theoretical models on the early universe have been extensively studied so far. On the other hand, because of the development of the technique, the accuracy of the experiments for observing the temperature fluctuations of the Cosmic Microwave background (CMB) is very increasing, especially in the one by Planck satellite whose first observational results were released in the last March. Since the fluctuations of CMB are related with the primordial curvature perturbations generated by cosmic inflation, we can test whether the very early universe is described by string theory or not, making use of the information of the temperature fluctuations of CMB. Therefore, the main goal of my project is to give predictions for the primordial curvature perturbations in theoretical models on the early universe based on string theory which can be tested by the observations by Planck satellite which continues the observations and is going to release updated data this summer. Especially, as concrete theoretical models on the very early universe which are based on string theory, we consider the theoretical models based on D-branes which are purely physical objects in string theory defined as end points of the open strings and the one including heavy fields which are natural outcomes of the scalar field potential appeared in the context of the string landscape.

2. Description of work achieved

There are several attempts to explain inflation out of superstring theory. The main recent development has been the ability to stabilize moduli fields to ensure the viability of inflation in string theory.

Among the inflation models, warped D-brane inflation model where cosmic inflation is driven by the motion of a D-brane in the warped extra dimensions gives very interesting predictions. It is well known that an effective theory of a D-brane is described by Dirac-Born-Infeld (DBI) action. When the warping of the extra dimensions is steep, since the non-canonical feature of the DBI kinetic term is not suppressed, the primordial non-Gaussianity generated in DBI inflation model was shown to be large [Alishahiha, Silverstein, Tong, 2004]. However, it was also shown that if we assume that the volume of the internal space is small enough, this original model was shown to be excluded by observations of the spectral tilt of the power spectrum, given that neither the primordial non-Gaussianity nor the gravitational wave has been detected.

For this, we thought that it was more natural to consider multi-field DBI inflation model because the internal space where the D-brane can move is six-dimensional and there is no reason to limit the dynamical degree of the freedom to be only one. Then, we had shown that it is possible to relax the constraint on DBI inflation by the multi-field effect [Arroja, Mizuno, Koyama, 2008]. However, in order to realize this possibility, a parameter representing how efficiently the original isocurvature perturbations are converted into the curvature perturbations must be large and whether one can obtain such large value depends on the models. For this, we have built a concrete multi-field DBI inflation model to meet the observational constraints making use of the waterfall potential [4]. Furthermore, although the formalism I had developed before is suitable to pick up the leading order effect, for Planck observations, it had been necessary to give predictions including the next order effect in perturbations. For this, I found that the members of LPT had developed the formalism to pick up the effect of the second-order perturbations in multi-field inflation whose kinetic terms are canonical [Tzavara, van Tent, 2012]. Therefore, by combining these two formalisms, we developed a formalism which can pick up the effect of the second-order perturbations in multi-field DBI inflation [7].

Although DBI inflation has a direct link with string theory as it is, recently, [De Rham, Tolley, 2010] had showed that DBI model where only the tension of the D-brane is taken into account belongs to a subclass of more general models, so-called DBI Galileon where the Lavelock combination of the brane can be considered as well in the higher dimensional set-up. For such kind of DBI Galileon model, we first studied the cosmology by applying this model to inflation and analyzed the amplitude of the power spectrum as well as the leading order effect of the primordial non-Gaussianity [1]. Especially, we showed that this model is a first concrete theoretical model which can predict orthogonal type non-Gaussianity coming from the bispectrum for some parameter region. We also gave forecast for the amplitudes of non-Gaussianity coming from the bispectrum with the special concentrations on the equilateral and orthogonal type ones in Planck experiments by calculating the Fisher matrix. We think that this result is interesting as the error bar becomes smaller and the original DBI inflation model is rejected even without requiring the small volume of the internal space, given that the central values of the amplitude of non-Gaussianity coming from the bispectrum for the equilateral and orthogonal types is unchanged from the latest CMB observations by WMAP [5].

On the other hand, because of the derivative interactions, the non-Gaussianity from the bispectrum in DBI inflation and DBI Galileon inflation is characterized as equilateral type for most of the parameter region. And in order to distinguish these models with other models like Ghost inflation and Horava-Lifshitz gravity model which also predict equilateral type bispectrum, I showed that the non-Gaussianity from the trispectrum also become important [2].

In superstring theory 6 extradimensions behave as scalar fields in the 4 dimensional effective theory which is obtained by the compactification and the property of these fields are classified by the masses of the fields. Previously, based on the knowledge of the quantum field theory in the flat spacetime, the fluctuations of the fields whose masses are heavier than the Hubble parameter are regarded to be negligible during the inflation. However, from the viewpoint of the string landscape, the scalar field potentials which appeared as the moduli stabilization can naturally possess the turning trough. Recently, it had been shown that when the trajectory of the inflaton deviates from the geodesics in the field space, we can no longer neglect the coupling between the light fields and heavy fields [Tolley, Wyman, 2009]. Concretely, they showed that when the turn is sufficiently soft and the deviation of the trajectory from the potential minimum is not so large, one can describe the system as if it included only the light degree of the freedom and the light field effective theory is characterized by the suppression of the sound speed. They also showed that the resultant power spectrum of the curvature perturbations possess oscillations in wave number when the light field effective theory is valid. But they did not show the criteria about the validity of the light field effective theory works and not give the predictions when the light field effective theory no longer works.

For this, recently, we considered a simple multi-field model with canonical scalar fields where there exists a mass hierarchy and a sudden turn in the inflaton trajectory with a finite time scale. Then, we showed that whether the effective theory is valid depends on the ratio between the mass of the heavy field and the time scale of the turn in the inflaton trajectory. We also clarified the oscillating features on the power spectrum of curvature perturbations for the sharp turn case where the effect of the heavy field is so important that the light field effective theory is no longer valid [3].

The essential point in the sharp turn is that the heavy field is excited even at the level of the background and we need to take into account of this degree of freedom until it decays after the subsequent damped oscillations. Although not specified to this framework, there had been some works where the primordial curvature perturbations are enhanced through the resonance with these background oscillations, which gives sufficiently large features in the primordial power spectrum of the curvature perturbations which can be detected in the future CMB experiments [Chen, 20011, 2012]. For this, we carefully investigated the system, and showed that at least for the set up where the background heavy field oscillations are excited by the sharp turn, contrary to the prediction by the previous works, the feature by the resonance is almost negligible [6].

3. Publications

1. Sebastien Renaux-Petel, Shuntaro Mizuno, Kazuya Koyama, “Primordial fluctuations and non-Gaussianities from multifield DBI Galileon inflation``, Journal of Cosmology and Astroparticle physics, IOP, **1111**, 042, November, 2011

2. Keisuke Izumi, Shuntaro Mizuno, Kazuya Koyama, “Trispectrum estimator in various models of equilateral type non-Gaussianity``, Physical Review, APS, Physical Review, APS, **D85**, 023521, January, 2012

3. Xian Gao, David Langlois, Shuntaro Mizuno, “Influence of heavy modes on perturbations in multiple field inflation``, Journal of Cosmology and Astroparticle physics, IOP, **1210**, 040, October, 2012

4. Taichi Kidani, Kazuya Koyama, Shuntaro Mizuno, “Non-Gaussianities in multi-field DBI inflation with a waterfall phase transition``, Physical Review, APS, Physical Review, APS, **D86**, 083503, October, 2012

5. Kazuya Koyama, Guido Walter Pettinari, Shuntaro Mizuno, Christian Fidler “Orthogonal non-Gaussianity in DBI Galileon: constraints from WMAP9 and prospects for Planck``, arXiv: 1303.2125 [astro-ph.CO]

6. Xian Gao, David Langlois, Shuntaro Mizuno, “Oscillatory features in the curvature power spectrum after a sudden turn of the inflationary trajectory ``, Journal of Cosmology and Astroparticle physics, IOP, **1310**, 023, October, 2013

7. Eleftheria Tzavara, Shuntaro Mizuno, Bartjan van Tent “Covariant second-order perturbations in generalized two-field inflation``, arXiv: 1312.6139 [astro-ph.CO]

4. Relevance of the project within P2IO

I understand that Prof. van Tent in the cosmology group of LPT plays a very important role in P2IO for the analysis of the CMB observation by Planck satellite. In this sense, I think the collaboration with him and his student Tzavara [7] is directly related with the project within P2IO. In this work, by extending the covariant formalism they had developed before [Tzavara, van Tent, 2012], we obtain the methods to pick up the second-order effect for the calculation of the curvature perturbations in general multi-field inflation models which include multi-field DBI inflation. Including Prof. van Tent, I know there are many researchers involved in the analysis of the CMB observation by Planck satellite within the scheme of P2IO and they would be happy to test predictions of interesting theoretical models on the early universe. During the period I was supported by P2IO, in addition to [7], I considered mainly 2 large topics. One is the non-Gaussianity of the primordial perturbations in the inflation model based on the dynamics of D-brane, like DBI inflation and DBI Galileon inflation. The other is features on the power spectrum of the primordial curvature perturbations which is caused by the heavy modes excited by the non-trivial inflaton trajectory in the field space which naturally arise in the context of string landscape. I think such works on theoretical predictions are very good set-up for them to test and in this sense these works also contribute indirectly to the project within P2IO.

7. Position after P2IO

From September in 2013, a posdoc at APC paris 7.
From April in 2014, an assistant professor at Waseda University in Tokyo.