The Global COE Program

"The Next Generation of Physics, Spun from Universality and Emergence"

Bilateral International Exchange Program (BIEP, invite) report

Send report to: Your responsible Professor in Kyoto University

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(Year/Month/Day)______ 2010/1/15_______

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Research Project

Title	The generation and evolution of cosmological perturbations from the inflationary universe
Duration	October 22th, 2009 to January 19th, 2010

Please summarize your activities and results during your stay in Kyoto University.
Also please describe how your stay has been beneficial to the graduate students in the institute. You can add a sheet, if you need more space.
You can also write any comments and requests to the GCOE program.

1. Background of the study

The classical big bang cosmological model explained the observational results such as the abundance of light elements very well. However, there still exist some problems, for instance, horizon problem and flatness problem in this model. Meanwhile, with the development of particle physics in 1970s, some new problems like monopole problem were found. Thus, some new models were emergently needed to overcome these fatal problems.

In early 1980s, inflationary model was proposed.[1] In this new mode;, the problems mentioned above were solved successfully by assuming a period of accelerated expansion during which the equation of state $w<1/3$. Most importantly, however, the inflationary paradigm gave rise to a predictive theory of the origin of the primordial cosmological perturbations.

More specifically, Current models of inflation are based on using general relativity as the theory of space-time, and making use of a scalar matter field to generate the phase of accelerated expansion. According to this mechanism, at the beginning of inflation, all classical matter present red-shift, so it is reasonable to assume that perturbations emerge as quantum vacuum fluctuations. Then, it produces an almost scale-invariant spectrum of cosmological perturbations. Thus, the first key requirement on a theory of structure formation which can explain current data is satisfied.

However, there still exist some problems in inflationary theory.[2] The first is the presence of an initial singularity, which makes inflationary scenario not able to provide a complete description of the early universe. Another problem is the so-called trans-Planckian where the physical wavelength observed today is less than the Planck length at the beginning of inflation, provided that inflation lasted just a few e-foldings of expansion more than what is required to solve the homogeneity and flatness problems.

2. Present situation of the theories

There are two ways to solve the problems arising in inflation. The first is to add some new elements to inflationary scenario. For example, k-inflationary model,[3] where a large class of higher-order scalar kinetic terms can drive an inflationary evolution without the help of potential terms.

Another way out is to propose new models other than inflation. Among these models, ekpyrosis is thought to be the most hopeful theory.[4]

In ekpyrotic model, contraction of the universe is assumed to happen in a short period of time before the big bang, while inflation is not needed after it. However, in the standard ekpyrosis, the spectrum for the curvature perturbation with a single canonical scalar field is necessarily blue,[5] which is inconsistent with the CMB observation.

Recently, a new ekpyrotic model is proposed.[6] Unlike the requirement of at least two scalar fields and a two-step process to obtain a scale-invariant spectrum in the past,[7,8] in the new model a scale-invariant spectrum of curvature perturbations is generated via adiabatic mechanism, based on a single, canonical scalar field. In the context of studies of the new ekpyrotic model, it has been realized that the scale-invariant curvature perturbation are generated during the "transition phase", a period before the standard ekpyrosis, lasting from the positive constant term dominating to the exponential dominating, which is different from the conventional ekpyrotic phase.

Thus, it is extremely important to check whether the conclusion drawn in this new model is true or not. Also it is important to compare the results with observational data to check the validity of this new theory.

3. Studies and conclusions

Firstly, we use the delta-N formulism to find the curvature perturbation in ekpyrosis. Though we also find the scale-invariant spectrum of curvature perturbation, one problem arises when we turn to calculate its local non-Gaussian function f_{NL}^{local}. It is found that f_{NL}^{local} is dependent on the freezing-out time,

$$f_{NL}^{local} = \frac{5}{2\sqrt{3V_0}t}$$

which means that the curvature perturbations will not be conserved in nonlinear case.

Thus, we turn to consider the validity of linear perturbation theory in ekpyrotic scenario. It is found that near the end of transition phase, linear perturbation of matrix will be much larger than unity,

$$A \approx c^2 \times 10^{-5} > 10^{50}$$

which means that linear perturbation theory is completely invalid at that time. It is also the same situation with the perturbation of energy density.

$$\delta\rho \approx -c^2 \times 10^{-15} > 10^{40}$$

So all the quantities calculated in this ekpyrotic model is unreliable at all.

4. Further implications and future studies

The invalidity of linear perturbation theory in ekpyrosis is a disaster, but it does not necessarily mean that this model has to be ruled out. We could make a more general discussion on some properties in this scenario in geometric way. It has been mentioned that perturbations in coordinate system can be constructed in a pure geometric way with general definition. The discussion of validity of such general quantities in ekpyrotic model should be one of the main studies in our future work.

5. What I have learnt

During these 90 days staying in Yukawa Institute for Theoretical Physics, I studied the cosmological perturbation theory in inflationary scenario in detail under Professor Sasaki's direction. It is the discussion with him that made me able to learn not only those established theories, but also the frontiers of new theories and ideas such as ekpyrosis, which is far beyond my imagination before visiting. Also I learnt the way to deal with formulas for perturbations, which is critical for my future works.

Not only on academics, I have also learnt a lot on Japanese culture and customs during my stay. Since Kyoto is the city with such a long history, many well preserved historical buildings and temples made me able to touch the traditional Japanese culture closely, rather than watch those photos from books and television. So now I can understand how Japanese people think of everything much better than before..

6. Acknowledgements

I would like to thank Kyoto University and staffs of the Global COE Program for giving me the chance to stay in the Yukawa Institute for Theoretical Physics for 90 days. Particularly, I wish to say thousands of thanks to Professor Misao Sasaki. It is his profound knowledge and patient direction that made me learn the way to deal with cosmological theory from the beginning. Also I hope to thank all the members in the cosmological group. It is their kindness and hospitality that made my dairy lives full of happiness. Finally, many thanks to Miss Tsuruhara for her careful preparation and arrangement which made my trip convenient. I am looking forward to visiting Kyoto University and the Yukawa Institute for Theoretical Physics again if there is a chance in the future.

7. References

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