I am a theoretical physicist working on cosmology in conjunction with the theory of the elementary particle physics. My main interest is to investigate on the high-energy physics through the inflationary mechanism both from the theoretical and observational aspects.

Inflation is an accelerated expansion of the early universe, realizing the highest energy which we can access. Therefore its comprehension gives us much implication of the high-energy physics. The key imprint of inflation is the primordial curvature perturbations as seeds of cosmological structures. Their further precise prediction is an imperative subject in response to future observational projects. I am interested in their statistical properties (e.g. the non-Gaussianity) and phenomena of their observables (e.g. the galaxy/halo bias) beyond the perturbative expansion with use of the superhorizon physics. I have so far proposed a non-perturbative algorithm for the power spectrum of the curvature perturbations in the stochastic formalism [1], and shown several examples with use of the cluster computers in Institute for Cosmic Ray Research [2].

As another attractive phenomenon related with the curvature perturbations, primordial black holes (PBHs) have been recently refocused on more and more. PBHs are theoretically suggested which might be produced due to large curvature perturbations. Therefore their abundance is strongly related with the inflationary models as well as they can simply play an important role as astrophysical objects. Recent remarkable development on observational instruments allows us to close in on the scenario that dark matters (DMs) consist of PBHs, while the first direct detection of gravitational waves (GWs) by LIGO/Virgo collaboration sheds light on the possibility that the observed massive black holes might be primordial ones [3–5]. I have so far investigate the PBH formation in several inflationary models, like hybrid inflation [6] and double inflation in the supergravity (SUGRA) framework [7, 8]. Also, as a new phenomenon of PBHs, I have considered their non-linear bias and constrained their abundance in connection with isocurvature perturbations [9].

Finally, I have also worked on several particle production mechanisms as a different imprint of inflation. In particular, I have concentrated on helical vector/tensor production during inflation and its relation with cosmic magnetic fields [10] or baryon asymmetry for example. Also I am interested in building or understanding the inflationary models themselves in terms of both particle physics and modified gravity.

Inflationary Perturbation Theory

Primordial inflationary mechanism has been a leading paradigm to describe the physical conditions that prevailed in the earliest stage of the universe. Despite its great success, the specific model or mechanism of inflation has not been revealed yet. To distinguish a lot of inflationary models, further surveys of primordial perturbations on smaller scale or their non-Gaussianity (NG) will be a main topic of cosmology. Accordingly, their theoretical prediction is also an important subject. We have so far worked on the non-perturbative method for the curvature perturbations on the superhorizon scale during inflation with use of the stochastic and δN formalism. Successfully we have proposed a new algorithm to calculate the power spectrum of the curvature perturbations without the perturbative expansion with respect to the inflaton fields [1], and shown an example in hybrid inflation which is the first quantitatively correct calculation [2]. Inspired our works, several authors discussed its extension and analytic comprehension (e.g. see Refs. [11–13]).

As well as the power spectrum, the bispectrum of the curvature perturbations is also important as the lowest order NG signature. In particular, its squeezed limit includes crucial information in terms of particle physics since it corresponds with the soft particle exchange and indicates the existence of extra light degree of freedom during inflation. In 2003, Maldacena proved that even the simplest single-field slow-roll model does show a slow-roll suppressed but non-zero squeezed bispectrum [14]. On the other hand, several authors have recently claimed that it can be absorbed into the rescaling of the coordinate and the small scale dynamics in local patches does not affected by that bispectrum [15, 16]. Even in multi-field cases, such a discordance is critical to connect the observables with the inflationary models. Following these circumstances, we have studied this *gauge artifact* effect in the δN formalism and proposed the algorithm with which the rescaled bispectrum can be directly obtained [17].

Primordial Black Holes

Recently the attention to PBH increases more and more since its possibility for a main component of DM has been still opened in a light mass region $\sim 10^{-10}M_\odot$, while it has been suggested that the LIGO's events can be explained by binary PBHs whose masses are around $\sim 10M_\odot$ where $M_\odot$ represents the solar mass. So far we studied the PBH formation in the hybrid inflation type potential as a simple example of multi-field inflation at first [6]. With use of the non-perturbative algorithm mentioned in the previous section, we found a strong no-go result that detectably massive PBHs ($\gtrsim 10^{-18}M_\odot$) cannot be produced in proper abundance with any parameter combination. Next we proposed a noble chaotic-new double inflation in the SUGRA framework, in which PBHs can be safely produced in any mass region and in any abundance [7]. Furthermore we pointed out that, in some parameter, the power spectrum can have a small second peak, with which the PBH-DM on light mass $\sim 10^{-10}M_\odot$ and massive binary PBHs on $\sim 10M_\odot$ can be realized simultaneously.

Also I am interested in the PBH's spatial distribution. Following the standard calculation of the galaxy/halo bias, we studied the modulation of the PBH distribution due to long-wavelength density perturbations, and we found that, the PBH number density can strongly traces the long-wavelength mode if there is a correlation between the long- and short-wavelength (PBH formation scale) modes from the squeezed bispectrum [9]. If such modulations appear on the CMB scale, PBHs cannot be a main component of DM since such perturbations should be detected as the matter isocurvature perturbations, while the matter isocurvature modes have been severely constrained by Planck collaboration.

Other Issues

Other than above two main themes, I have so far studied many topics. At first I have been working on helical vector/tensor particle production during inflation with the Chern-Simons type coupling. That coupling yields a tachyonic instability for either helical mode of the gauge field through the inflaton's time derivative, and then that mode can be strongly amplified. In Ref. [10], we considered the resonance amplification of U(1) gauge field in this model at the end of inflation and oscillation phase after inflation, and suggested that current void magnetic fields might be explained by this resonance, avoiding the CMB observational constraints. Following our work, e.g. Ref. [18] investigated our model more precisely with use of lattice simulations and supported our claims.

In Ref. [19], we worked on the correlation between temperature and spectral μ-distortion of CMB given by NG neutrino isocurvature density modes. Also in Ref. [20], we reconsidered the effect of small scale density perturbations on the big-bang nucleosynthesis and found that the dependence of the ^{4}He abundance considered previously [21] is qualitatively wrong.

Ongoing and Future Work

Among the several observational missions in future, the precise determination of NG will be one of the main topics necessarily. From the theoretical aspect, it is important to predict specific observables directly related to inflationary models since there are *gauge artifact* subtleties I mentioned for small NG. However current existing works basically focus only on the simplest case, i.e. single-field slow-roll inflation. Therefore I intend to work on several observables like the galaxy/halo bias for small but non-zero NG models, extending my work [17]. Also I will study the stochastic effect on NG since the non-perturbative correction will be non-negligible for higher order NG.

Regarding PBH projects, it is now a key subject to distinguish the GW events from binary PBHs and those from standard black holes in LIGO's data. We are working on these topics, concentrating on spin properties of PBHs for example.

Helical particle production is also now a hot topic. We are working on the GW amplification in the low scale inflationary model where a spectator field has a coupling with a SU(2) gauge field in the Chern-Simons term. We have so far found detectable GWs can be given even in extremely low scale inflation in such a setup. Since those GWs are fully helical, I am also interested in the detection method of such helical GWs.

Finally, as a pure theoretical approach for inflation, the interpretation of R^2-type inflation is interesting. Since Planck's results support concave models, the universe might have asymptoted to the exact de Sitter spacetime as a pure R^2 theory in the earliest stage. From these prospects, we are working on the gravitational quantum correction around the de Sitter background and its possibility of breaking the pure de Sitter, which might realize slow-roll inflation effectively.

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