Research plan

The aim of my research in the long-term point of view is the understanding of gravity at the quantum level. It is well-known that there is a serious difficulty in the canonical quantization of gravity. At least at the level of perturbation theory, we can obtain finite results on scattering amplitudes if we work in the framework of string theory. Therefore, a natural expectation is that further study on string theory would be the way to achieve the above-mentioned goal.

Based on recent researches, it is expected that a kind of gravity theories can be described by some quantum field theories via AdS/CFT correspondence. In fact, the understanding of AdS/CFT corresondence is still phenomenological. However, it predicts many non-trivial quantitative relations between gauge theory and gravity, and moreover, some of them have turned out to be correct. Therefore, it is natural to expect that one can gain insights into quantum theory of gravity through a deeper understanding of AdS/CFT correspondence. In addition, it would be also valuable to study some issues in string theory as long as they include gravity in an essential manner.

1. Chern-Simons-matter matrix models

There are researches on three-dimensional Chern-Simons-matter theories (CMS) as they are supposed to describe four-dimensional quantum theory of gravity. They form a family of three-dimensional gauge theories, including various kinds of theories. So far, only a small part of them, even though they do not look special as quantum field theories, have been studied. I will extend the range of research on CMS, and try to clarify which properties of CSM is crucial in the relation to quantum theory of gravity. In my recent researches, I investigated non-perturbative properties of CSM through the study of matrix models which are deeply related to CSM. I expect that a further research would reveal differences between CSM with dual gravity and the ones without dual gravity. In fact, I have succeeded to extend the region of applicability of the matrix model technique to CSM, so I think that further systematic study would be possible.

Up to now, I have focused on behaviors of observables in the strong coupling regime. However, the research on the weak coupling expansion would also have useful information. It is well-known that one can read off the information of instanton effects from the asymptotic behavior of the perturbative series. Instanton effects in string theory are known to be related to the topology of the space-time in which string are moving, so such information would be important to know some details of the space-time described by a dual gravity. A related study has been done by Nagoya group. My research will investigate various kinds of CSM systematically, instead of focusing on a particular theory and obtaining quantitative results. Recently, there are intensive researches on the relation between the perturbative series and non-perturbative effects under the name of "resurgence." An application of such a mathematical results would be helpful.

2. The characterization of $\mathcal{N} = 4$ super Yang-Mills theory

$\mathcal{N} = 4$ super Yang-Mills theory is the example of AdS/CFT correspondence which has been the most intensively studied so far. This theory has a large symmetry which controls various properties of the theory. Then, it would be natural to guess that the AdS/CFT correspondence might be just a consequence of the symmetry. However, the relations studied so far do not seem to be such trivial things. To clarify this issue, it would be important to distinguish truly non-trivial consequences of AdS/CFT correspondence from simple kinematical ones. For example, correlation functions are assumed to have counterparts in gravity theory, but some numerical coincidences of them would be non-trivial depending on how much ambiguity exists in the solution of the bootstrap equations.

It seems to be a very important step to characterize $\mathcal{N} = 4$ super Yang-Mills theory for understanding AdS/CFT correspondence in a deep level. Recently, there are many developments on understanding non-local operators which could be the beginning of a new stage of understanding quantum field theory. Also, many researchers are recently interested in an analysis of correlation functions in a quite general setting. Based on those achievements, I would like to try to discuss superconformal field theories including $\mathcal{N} = 4$ super Yang-Mills theory. It would be still difficult to perform such a general analysis in terms of the current techniques, but it might be possible to gain some insight for a limit in which the central charge is large. The results in this limit would be already very important.

3. Closed string tachyon condensation

Any closed string theory contains the gravitational interaction. If a tachyon appears in such a theory, then its condensation would affect the background space-time. In fact, many researches suggest that a tachyon condensation would induce a drastic deformation of the space-time. Therefore, it would be quite helpful to investigate the condensation of closed string tachyons for understanding the gravitational interaction in string theory. I would like to try extending my research further to understand more about the mechanism of tachyon condensation and its results.