Research History

I have been mainly studying matrix model (statistical system with matrices as dynamical variables) with bearing in mind that it would provide nonperturbative formulation of quantum gravity, or string theory.

String theory is the most promising candidate of unified theory of four fundamental interactions in the world including gravity. However, string theory has only perturbative definition, and because of this, it does not have predictive power for our real world. **This is the biggest problem in string theory and it has not been resolved for more than twenty years.** In order to answer fundamental questions string theory should do, like why our space-time has four dimensions, or how our universe began, it is essential to give nonperturbative formulation of string theory.

In recent studies of string theory, it is proposed that string theory would be nonperturbatively formulated by large$-N$ limits of matrix models (N is the rank of matrices), but they are still incomplete. I have been studying matrix models and related physics aiming at completing it. The main results of my research are as follows:

1. **Analysis of emergence of four-dimensional space-time in the IIB matrix model by mean-field approximation**
2. **Description of nonperturbative effect in noncritical string theory in terms of matrix models and loop equations**
3. **Analysis of spontaneous breaking of supersymmetry in noncritical superstring theory**

In **1**, we first developed new extension of mean-field approximation and by applying it to the IIB matrix model proposed as nonperturbative formulation of string theory, **we obtained strong evidence that in the large$-N$ limit, the rotational invariance in ten dimensions would be spontaneously broken down to that in four dimensions. This result suggests that progress in research of string theory has been made so that it may answer the fundamental question why our space-time has four dimensions.**

In **2**, we pointed out that in $c = 0$ noncritical string theory, a D-brane (soliton in closed string theory) corresponds to an instanton in a matrix model and **computed its weight in the free energy, namely chemical potential exactly.** Moreover, **we proved that this quantity is universal** in the sense that it does not depend on details of potential in the matrix model. In spite of this, we showed that in other approaches than a matrix model, like a closed string field theory or differential equations (Painlevé equations) which low dimensional quantum gravity satisfies, the chemical potential cannot be calculated in principle. **This fact strongly suggests that fundamental degrees of freedom in string theory are not closed strings, but matrices.**

In 3, **we showed that in a supersymmetric matrix model, its supersymmetry is spontaneously broken by instanton effect, by calculating an order parameter exactly using the orthogonal polynomial technique.** Moreover, we showed that correlation functions in this model reproduce those in a two-dimensional noncritical superstring theory and hence **pointed out that the former is likely to provide a nonperturbative formulation of the latter,** These results imply that in this superstring theory, supersymmetry which is preserved at all orders in perturbation theory is spontaneously broken by nonperturbative effect. Therefore **our study is the first example in which spontaneous breaking of supersymmetry can happen concretely even in string theory and as such it is epoch-making.** In fact, **I was awarded the eighth Seitaro Nakamura prize by Soryushi Shogakukai, for my paper summarizing these results as a single author.** Moreover, recently we found that correlation functions in our matrix model can be expressed in terms of those in the random matrix theory and we are continuing research of this model based on this fact.

To summarize, **I am proud that I have been making a research which blazes a trail in analyzing dynamics in the large-N limit, in particular spontaneous symmetry breaking there.**