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（様式3'）

博士論文の要旨

氏　　名　太田 光

論文題目 Dynamics of Revolving D-branes

As widely known, superstring theory is the promising candidate for the quantum gravity. In the history of the theory, there are some "revolutions". Even among them, the discovery of the D-brane is remarkably significant.
D-brane is the key subject to understanding the non-perturbative nature of string theory along with the various dualities. Since it was found in 1995, a variety of works that investigate or make use of the D-branes have been published.
The important feature of D-brane is that open strings can have the end on it. The low energy effective theory of these open strings gives the field theory on the Dp-brane world volume. Considering the various configurations of D-branes, many attempts that gives the geometrical understanding of supersymmetric gauge theories or realize our four- dimensional universe on it have been done.
In spite of the elaborate investigations over the last 30 years, we hardly know the dynamics of D-brane yet. For simple configurations, like static parallel case, tilted case or moving with a constant velocity case, we know how to calculate the effective potential which arises between D-branes. It is given as the one-loop effective potential of open strings stretched between D-branes or the amplitude for the exchange of massless fields between them. For the D-branes with acceleration, however, it had not known how to calculate the effective potential.
Many of the models so far is based on the static D-branes that preserves the supersymmetry. For the static D-branes, the system which violate the supersymmetry becomes unstable unless performing special manipulations like the orientifolding. Considering the moving D-branes, we can innovate a new mechanism to stabilize D-brane systems and afford the possibility that spreads the directions to describe the open questions of our four-dimensional universe, like the hierarchy problem, the cosmological constant problem and so on. %from the string theoretical perspective.

In this thesis, as a first step to fully understand the D-brane dynamics and describe the four-dimensional theories on which, we concentrate on a pair of D-branes which revolving around each other in a flat spacetime.
For static parallel D-branes, which is a BPS state, there is no potential because of the supersymmetry. By rotating them, the supersymmetry is broken and an attractive force arises.
Naively, we can guess that these revolving D-branes compose a bound state due to

balancing the attractive force arises from strings stretched between them and the centrifugal force.

If the distance between both of D-branes, which gives the vacuum expectation value of a scalar field of the D-brane worldvolume theory, is sufficiently smaller than the Planck scale or the string scale, it follows that this model describes the origin of the electroweak scale from the string theoretical perspective.

Therefore, it is required to calculate the effective potential for these revolving D-branes for investigating whether a bound state exist.

As I mentioned above, however, the method to calculate the D-brane effective potential is not sufficiently known yet. A main obstacle to calculate it is the difficulty of quantization of open strings between D-branes for general configurations. For open strings attached on accelerating D-branes, boundary conditions to become complicated as explained in the following chapters. To avoid this difficulty, we can employ two kinds of method.

One of them is performing the perturbative calculation in the rotating coordinate. By employing the rotating coordinate, boundary conditions for open strings become negative in exchange for simplicity of the equation of motions. Then we can perform the mode expansion of operators and calculate the effective potential perturbatively. For perturbative calculation in the Heisenberg picture, however, there are secular terms that are monotonic increasing function of the time and violate the validity of perturbation in operators and the Dyson series. Therefore, we developed the improved perturbation method by which secular terms is systematically removed and we can get the appropriate result. Using this method, we calculate the effective potential for revolving D-branes and see that it is governed by the distance and the angular frequency.

The other method is the partial modular transformation. In general, string amplitudes have the modular invariance and interpreted in both of the open and closed channel. The partial modular transformation is performing the modular transformation in a part of the modular integral. Using this method, we can approximate the amplitude which gives the effective potential for D-branes with the sum of the contributions from the open massless modes and closed massless modes with a good accuracy. Each contribution can be calculated in the low energy descriptions, namely, the super Yang-Mills theory for open strings and the supergravity for the closed strings. Therefore, we can obtain the effective potential without quantize the open strings between D-branes exactly. Furthermore, we can investigate the short distance behavior of the effective potential which is significant to consider the possibility of bound states.

Besides, from the worldvolume theory point of view, the contribution of closed massless modes is interpreted as the threshold correction of all of massive open modes. We can see that the leading term of this correction is the fourth term of the relative velocity of D-branes which decide the SUSY breaking scale for general trajectories. This fact also might be the key to understand the origin of the electroweak scale and its stability against the physics at the high energy scale.

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Results of the doctoral thesis screening

博士論文審査結果

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Title
論文題目　Dynamics of Revolving D-branes

D-ブレインはその発見以来、閉弦のテンソル場の源泉として、開弦が終端できる広がった物象として、あるいは超対称性に伴いゲージ重力対応の舞台となる反ドジッター空間を実現するものとして、現代の超弦理論の発展に深く関わってきた。特に、素粒子模型構築の歴史において、D-ブレイン世界の思想は階層性問題を解決する一つの可能性を示唆し、初期宇宙膨張のシナリオを与えるなど、多くの研究がなされてきた。

太田氏の学位論文は、このような2つのD-ブレインが互いに回転するときの動力学に関する研究である。以前より、ブレイン同士が互いに一定相対速度を持つ場合には、超対称性が破れて引力を生じることが知られていたが、互いに回転する場合のそれらの間の相互作用、束縛状態の有無やその性質などは未知の分野であった。このような回転ブレイン系は、超対称性を破る新しい機構を与え、束縛系のスケールにより階層性問題を解決することに道を拓く大変興味深いものであり、太田氏は一連の研究を行なってきた。

論文では回転する D-ブレインの有効作用を計算するための2つの新しい方法が議論された。一つ目は、回転するブレインの境界条件を取り入れた相互作用表示のハミルトニアンに現れる、展開次数とともに大きくなる“secular”項を避けるための、改善された摂動展開法である。また、もう一つは、閾値補正計算においてシュヴィンガーパラメータの区間を2つに分割し、一方だけをモジュラー変換して、開弦で紫外領域を、閉弦で赤外領域をそれぞれ良い近似で計算する「部分モジュラー変換」計算法である。どちらも明快で得られた結果もすばらしく、それらの結果はすでに査読付き英文雑誌に三編の論文として掲載されている。

太田氏はギリシャでの滞在研究経験もあり、国際会議において英語で口頭発表するなど、英語能力も十分備わっていることが認められる。以上の理由により、審査委員会は全会一致で本論文が学位の授与に値すると判断した。