A landscape in boundary string field theory: new class of solutions with massive state condensation†

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We solve the equation of motion of boundary string field theory allowing generic boundary operators quadratic in X, and explore string theory non-perturbative vacua with massive state condensation. Using numerical analysis, a large number of new solutions are found. Their energies turn out to distribute densely in the range between the D-brane tension and the energy of the tachyon vacuum. We discuss an interpretation of these solutions as perturbative closed string states. From the cosmological point of view, the distribution of the energies can be regarded as the so-called landscape of string theory, as we have a vast number of non-perturbative string theory solutions including one with small vacuum energy.

As a non-perturbative formulation of open bosonic string, boundary string field theory (BSFT)[1)] was proposed as well as cubic string field theory (CSFT). In general, solutions of string field theories are quite important as they would provide non-perturbative vacua of string theory, to look at the true capability of string theory.

Recently, the multiple D-brane solutions, which have greater energies than the trivial vacuum, were proposed in CSFT. It would have a significance equivalent to the proof of the original Sen's conjecture, since the D-brane creation is thought of as a necessary ingredient for a complete non-perturbative formulation of string theory. To climb up the SFT potential hill instead of rolling down the hill to get to the tachyon vacuum, it is indispensable to treat the string massive modes.

After the construction of the analytic solution for tachyon condensation, various analytic solutions in CSFT have been found. In recent times, analytic forms of lump solutions and multiple D-brane solutions were proposed. In BSFT, as well, an analytic solution for tachyon condensation and lump solutions have been found .

To solve the equation of motion of CSFT, we encounter the infinite-dimensional equation, which is hard to solve. In fact, there are some subtleties of proposed solutions. On the other hand, there is a consistent truncation scheme which reduces BSFT to a standard field theory with a finite number of fields. The BSFT action was constructed also for boundary interactions quadratic in the worldsheet field X, corresponding to a subset of massive modes of open string.

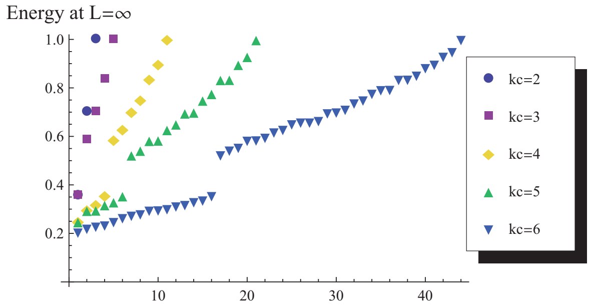

Fig. 1. The plots of the energies for Lorentz invariant solutions of the BSFT. Values are in units of $T_{25}V_{26}$ which is the total energy (tension) of a D25-brane. k_c is a cutoff integer for truncating the excited level considered in the BSFT.

The purpose of this paper is to solve the equation of motion of the BSFT action for the quadratic boundary operators. In contrast to CSFT, only the tachyon field plays a significant role in the BSFT exact solution for tachyon condensation and the lump solutions such that the analysis is rather simple. For this reason, it is natural to expect that one may obtain a new class of solutions by involving some more boundary operators, aiming at new string vacua and a construction of a multiple-D-brane solution.

We adopt the BSFT action for quadratic boundary interactions with arbitrary number of derivatives on the worldsheet, and solve the equation of motion numerically to find homogeneous static solutions. The condensation of the massive fields is taken care of to their all orders. So the solutions are non-perturbative ones at the classical level of SFT, in the same sense as for the non-perturbative tachyon vacuum solutions of the BSFT. We discover a large number of new solutions of BSFT. Interestingly, those energies turn out to be smaller than the D-brane energy, see Fig. 1. Our analysis strongly suggests the existence of an infinite number of solutions. We also find that an approximately uniform distribution of the energies of the solutions, which suggests a relation to closed string excitations at the tachyon vacuum. Furthermore, from a cosmological point of view, the distribution of infinitely many solutions is reminiscent of the so-called string landscape.

† Condensed from the article in PTEP 2013 (2013) 043B01

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