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Heterotic non-linear sigma models with anti-de Sitter target spaces

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Abstract

We calculate the beta function of non-linear sigma models with S^{D+1} and AdS_{D+1} target spaces in a $1/D$ expansion up to order $1/D^2$ and to all orders in α'. This beta function encodes partial information about the spacetime effective action for the heterotic string to all orders in α'. We argue that a zero of the beta function, corresponding to a worldsheet CFT with AdS_{D+1} target space, arises from competition between the one-loop and higher-loop terms, similarly to the bosonic and supersymmetric cases studied previously in [J.J. Friess, S.S. Gubser, Non-linear sigma models with anti-de Sitter target spaces, Nucl. Phys. B 750 (2006) 111–141]. Various critical exponents of the non-linear sigma model are calculated, and checks of the calculation are presented.

1. Introduction

Particular interest attaches to backgrounds of string theory involving AdS_{D+1} because of their relation to conformal field theories in D dimensions [2–4] (for a review see [5]). But because these geometries (with some exceptions) arise from the near-horizon geometry of D-branes, formulating a closed string description is complicated by the presence of Ramond–Ramond fields.

It was recently proposed [1] that AdS_{D+1} vacua might exist without any matter fields at all. Instead of relying upon the stress–energy of matter fields to curve space, the proposal is that higher powers of the curvature compete with the Einstein–Hilbert term to produce string-scale AdS_{D+1} backgrounds. The main support for this proposal comes from large D computations of

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the beta function for the quantum field theory on the string worldsheet. Before discussing these computations, let us review the lowest-order corrections to the beta function in an α' expansion:

$$\begin{aligned} &\text{bosonic:} && \beta_{ij} = \alpha' R_{ij} + \frac{\alpha'^2}{2} R_{iklm} R_j{}^{klm} + O(\alpha'^3), \\ &\text{heterotic:} && \beta_{ij} = \alpha' R_{ij} + \frac{\alpha'^2}{4} R_{iklm} R_j{}^{klm} + O(\alpha'^3), \\ &\text{type II:} && \beta_{ij} = \alpha' R_{ij} + \frac{\zeta(3)\alpha'^4}{2} R_{mhki} R_{jrt}{}^m \left(R^k{}_{qs}{}^r R^{tqsh} + R^k{}_{qs}{}^t R^{hrsq}\right) + O(\alpha'^5). \end{aligned} \tag{1}$$

These expressions are obtained using dimensional regularization with minimal subtraction, and all derivatives of curvature are assumed to vanish as well as all matter fields. Derivatives of curvature indeed vanish for symmetric spaces: for example,

$$R_{ijkl} = -\frac{1}{L^2}(g_{ik}g_{jl} - g_{il}g_{jk}) \tag{2}$$

in the case of AdS_{D+1}. One indeed finds non-trivial zeroes for AdS_{D+1} from all three beta functions in (1). An examination of higher order corrections in the bosonic and type II cases shows that the zero persists in the most accurate expressions for the beta function that are available at present; however its location changes significantly, converging to $\alpha' D/L^2 = 1$ as D becomes large. One aim of the present paper is to pursue similar large D computations in the heterotic case.

It should be clear from the outset that the question of the existence of AdS_{D+1} vacua with $\alpha' D/L^2$ close to unity is a difficult one to settle perturbatively. Fixed order computations are not reliable guides because the scale of curvature is close to the string scale. Large D computations with finite $\alpha' D/L^2$ seem to be a better guide, but they too could be misleading, mainly because higher order effects in $1/D$ than we are able to compute could change the behavior of the beta function significantly. These difficulties were discussed at some length in [1]. Also, the vanishing of a beta function such as the ones in (1) is only a necessary condition for constructing a string theory: one must also cancel the Weyl anomaly and formulate a GSO projection that ensures modular invariance and the stability of the vacuum.

There is a more general reason to be interested in high-order computations of the beta function on symmetric spaces: from them we can extract information about the structure of high powers of the curvature that is quite different from what is available from expansions of the Virasoro amplitude. While the latter tells us about terms involving many derivatives but only four powers of the curvature (because only four gravitons are involved in the collision), the former tells us about many powers of the curvature with no extra derivatives.

The organization of the rest of this paper is as follows. In Section 2, some general properties of the heterotic NLσM are discussed. In Section 3, the formalism and the results at $1/D$ order are presented. In Section 4, the critical exponents at $1/D^2$, the beta function, and the central charge of the CFT are computed. The appendices include a brief explanation of the method of the calculation for the diagrams needed and the values of these diagrams.

2. The heterotic non-linear sigma model

As in [1], much will be made of a connection through analytic continuation of the NLσM on AdS_{D+1} and the NLσM on S^{D+1}. If L is the radius of S^{D+1} and $g = \alpha'/L^2$, then continuing to