Higher Derivative Corrections in M-theory via Local Supersymmetry

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M-theory is a theory of membrane with $\mathcal{N} = 1$ supersymmetry in eleven dimensions, and the low energy effective action is described by $\mathcal{N} = 1$, $D = 11$ supergravity. Since M-theory is thought to be a strong coupling limit of type IIA superstring theory, many efforts have been made to formulate it as a theory of membrane. Although we do not yet know the perturbative formulation of M-theory, we expect that this theory contains higher derivative corrections to the $\mathcal{N} = 1$, $D = 11$ supergravity.

In fact these higher derivative corrections are expected from the perturbative analyses of type IIA superstring theory. According to these analyses a part of corrections to type IIA supergravity is given by

$$\begin{aligned}
&\mathcal{L}_{(\alpha')^3} \sim e^{-2\phi} I_{\text{tree}} + c\, I_{\text{1-loop}}, \\
&I_{\text{tree}} = t_8 t_8 e R^4 + \tfrac{1}{4\cdot 2!}\epsilon_{10}\epsilon_{10} e R^4, \quad I_{\text{1-loop}} = t_8 t_8 e R^4 - \tfrac{1}{4\cdot 2!}\epsilon_{10}\epsilon_{10} e R^4 - \tfrac{1}{6}\epsilon_{10} t_8 B R^4,
\end{aligned} \tag{1}$$

where c is a known constant. The tree level effective action is obtained by the four graviton amplitude and the sigma-model computation. The first two terms of the one-loop effective action is found by the four graviton amplitude. The last term in the one-loop effective action is introduced to ensure the string-string duality between type IIA on K3 and heterotic string on T^4. Under this duality, the last term is related to the Green-Schwarz anomaly cancellation term in the heterotic string effective action.

Thus we expect higher derivative corrections to $\mathcal{N} = 1$, $D = 11$ supergravity. Actually I showed that there are only two candidates

$$t_8 t_8 e R^4 + \tfrac{1}{4!}\epsilon_{11}\epsilon_{11} e R^4, \qquad t_8 t_8 e R^4 - \tfrac{1}{12}\epsilon_{11} t_8 A R^4, \tag{2}$$

which are consistent with the local supersymmetry. It is easy to see that the above two combinations completely match with the result obtained in string theory. This implies that the local supersymmetry is powerful enough to determine the structure of the M-theory. Note that eqs. (2) only correspond to the 1-loop terms in type IIA string theory, which do not have dilaton factors. In other words, R^4 terms are 1-loop exact and receive no contributions from higher than 1-loop amplitudes. This is non-vanishing theorem in string theory, which is proven here by the local supersymmetry.

Now I'm trying to determine the other terms which are the same order as R^4 and include four form field strength, such as $R^3 F^2$. Completion of the higher derivative terms at this order will give many new insights into black hole physics and gauge/gravity correspondence.