String perturbation theory in Ramond-Ramond backgrounds

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Based on Minjae Cho, MK 2311.04959

Surveying the Landscape

Summary of the talk

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- We found background solutions in SFT that corresponds to GKP type flux compactifications with small superpotential.
- With this "worldsheet" description, we can now compute stringy amplitudes in GKP backgrounds

Plan of the talk

- Introduction
- What is string field theory?
- Review of GKP
- SFT for GKP with small flux superpotential
- Conclusions

Chapter 0: Introduction

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- To me, this is unacceptable
- We should look forward and start thinking about how to do string theory in cosmological solutions

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  - Famously, RR backgrounds are notoriously difficult to study in RNS formalism
  - Physical observables are defined through S-matrix.
- This suggests that we may need to go beyond the first quantization approach to string theory
- Let's briefly review why it is difficult to study RR backgrounds in RNS formalism

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- The worldsheet action has $(0,0)$ picture

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- But, RR vertex opeartors have half-integer picture numbers.
- Thus there is no way one can deform the worldsheet just by using RR fluxes.
- Furthermore, any attempts to do so will induce a non-local deformation

$$g_s^2 \int_\Sigma d^2 z_1 V_{RR}^{(-1/2,-1/2)}(z_1) \int_\Sigma d^2 z_2 V_{RR}^{(1/2,1/2)}(z_2)\,.$$

- But, this does not yet imply that we cannot compute scatterings in background field method

String perturbation theory in RR backgrounds

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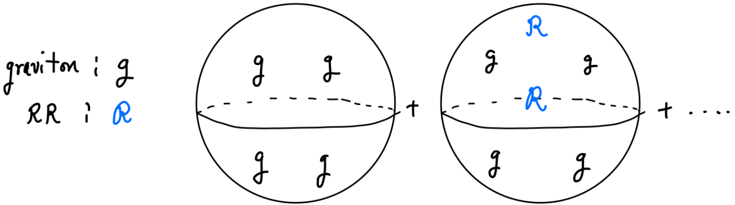
- Let's try to formulate four-graviton amplitude in RR backgrounds at string tree-level



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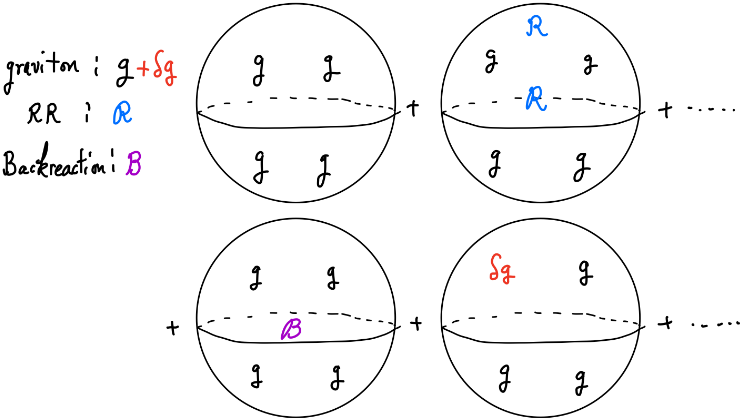

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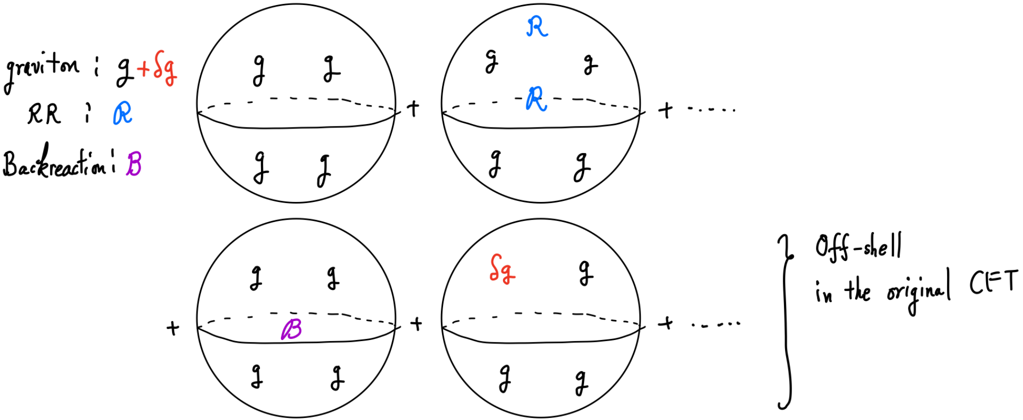

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- We should use string field theory!

Chapter 1: What is string field theory?

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- The SFT action, if there is a target-space interpretation, provides target space action of fields.

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- On shell states in bosonic string theory are constructed as

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- Then, one can construct string field Ψ, by

$$\Psi = Tc\bar{c}e^{ik\cdot X} + \epsilon_{\mu\nu}c\bar{c}\partial X^\mu \bar{\partial} X^\nu e^{ik\cdot X} + \ldots\,,$$

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  where polarizations are now taken as string fields.
- Crucially, in SFT, on-shell condition is not imposed and k can take an arbitrary value.

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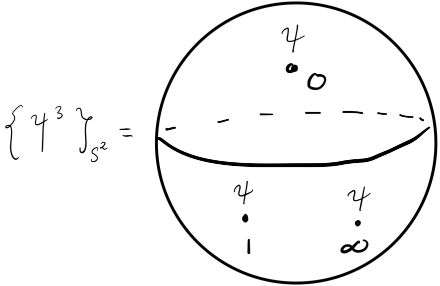
- The idea is to read off Feynmann vertices from off-shell scattering amplitudes

Three-point vertex

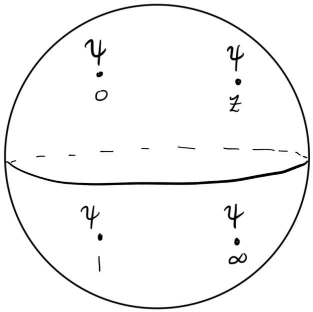
- The three point vertex is determined by the following off-shell amplitude



- $\{\Psi^3\}$ is a complicated function of polarization/string fields.

Four-point vertex

- To compute the four-point vertex, we need to do a little more work.
- Let's first compute four-point amplitude



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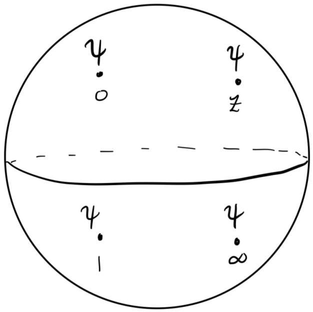

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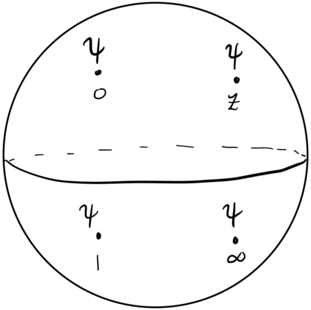
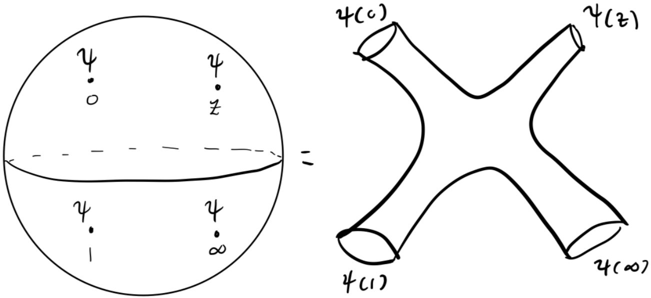


- We expect that some contributions to the four-point amplitude come from joining three-point vertices
- The goal is to isolate the contribution that comes purely from the four-point vertex

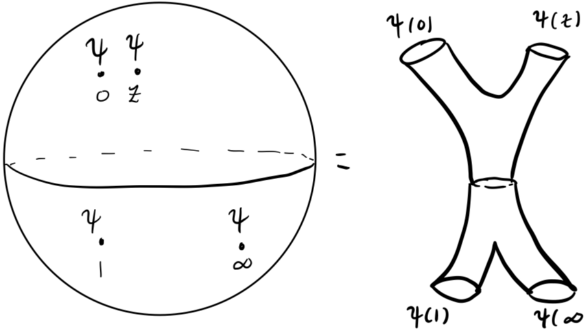
Four-point vertex

- We can put z at a generic point



- For generic z, we have a four-point vertex contribution

- We can bring z to 0



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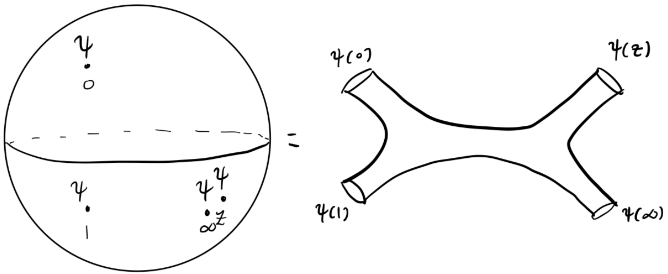
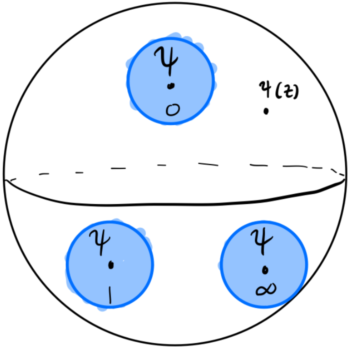


- When z is close to ∞, we have s-channel

Four-point vertex

- To find the four-point vertex contribution, we can excise local coordinate charts around 0, 1, ∞
- and integrate over z away from the blue regions

$$\{\psi^4\} = \int_{z \notin \bullet} d^2 z$$



- Different choices of local coordinates correspond to field redefinitions

What is string field theory?

- Finally, we have constructed string field action

$$S(\Psi) = -\frac{1}{2g_s^2}\langle\Psi|c_0^- Q_B|\Psi\rangle + \sum_{N,g}\frac{g_s^{2-2g+N}}{N!}\{\Psi^N\}_{\Sigma_g}\,.$$

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- In essence, SFT as we know is a self-consistent set of rules that allows off-shell computations in string perturbation theory
- The SFT action involves infinitely many terms for infinitely many field. So, we should carefully choose a problem

Why now?

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- As the first step, let us study flux compactification in type IIB string theory

Chapter 2: Review of GKP background.

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- The low-energy action contains the following terms

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- One can massage the above equations to obtain

$$S \supset -\frac{1}{2\kappa_{10}^2}\int_{\mathbb{R}^{1,3}} d^4X\left[\int d^6X\sqrt{-G}\,\frac{G_-\cdot\bar{G}_-}{\mathrm{Im}\tau}\right]\,,$$

$$\int_{X/\mathcal{I}} H\wedge F + N_{D3} = Q_{D3}\,,\;\; G_3 := F_3 - \frac{i}{g_s}H_3\,,\;\; G_- := G_3 + i\star_6 G_3\,.$$

What is GKP?

- The action contains

$$S_F = -\frac{1}{2\kappa_{10}^2}\int_{\mathbb{R}^{1,3}} d^4X V_F\,, \quad V_F = \left[\int d^6X\sqrt{-G}\frac{G_-\cdot\bar{G}_-}{\mathrm{Im}\tau}\right]$$

$$\int_{X/\mathcal{I}} H\wedge F + N_{D3} = Q_{D3}\,,\ G := F_3 - \frac{i}{g_s}H_3\,,\ G_- := G_3 + i\star_6 G_3\,.$$

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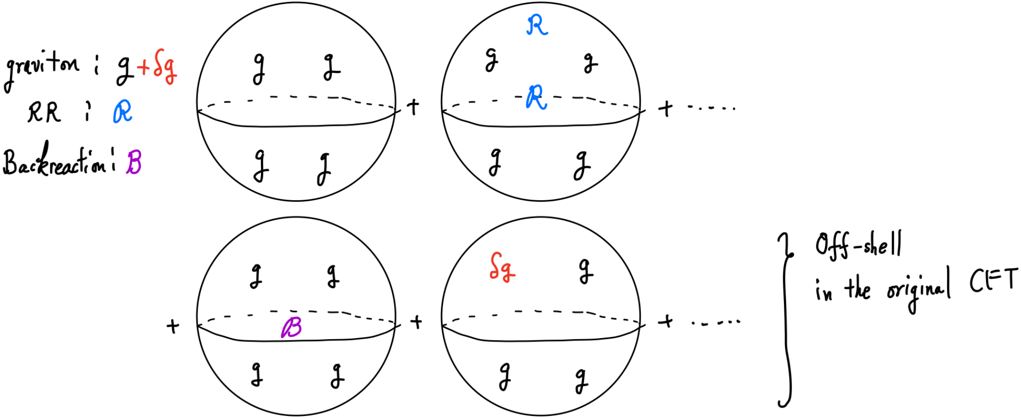
- At the minimum of the potential, one finds

$$-\star_6\frac{H_3}{g_s} = F_3\,.$$

Chapter 3: SFT for GKP.

Goal

- Today we will find the background solution $\equiv B$ in string field theory for GKP backgrounds
- and show that vacua with small flux superpotential admit double scaling expansion



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- With this CFT, we can construct SFT that involves infinitely many terms for infinitely many fields

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- We want to turn on *quantized* fluxes $F_3,\ H_3$ in SFT to find a nearby vacuum

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- Hence, it is absolutely crucial that the problem we want to solve is of a perturbative nature.
- But the background fluxes background fluxes $H_3, \ F_3$ are *quantized*
- If deformation by $H_3, \ F_3$ is not "small," we cannot solve eom in SFT in a reasonable manner

Puzzle

- Therefore, for us to find GKP solution in SFT, we need to ensure that we can treat quantized fluxes as a small perturbation

$$\delta\Psi = c\bar{c}H_{ijk}Y^i e^{-\phi}\psi^j e^{-\bar{\phi}}\bar{\psi}^k + g_s c\bar{c}e^{-\phi/2}\Sigma_\alpha F^{\alpha\beta}e^{-\bar{\phi}/2}\overline{\Sigma}_\beta \,.$$

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- Naively, this seems to suggest that we cannot treat quantized fluxes as a perturbation.

Resolution

- Let's look at OPEs of the worldsheet fields

$$Y^i(x)Y^j(0) \sim -\frac{\alpha'}{2}G^{ij}(z)\log|x|^2\,,\;\; \psi^i(x)\psi^j(0) \sim \frac{G^{ij}(z)}{x}$$

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- Following Demirtas, MK, McAllister, Moritz 19 (PFV), one can choose H and F such that

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- By taking the following double scaling expansion

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we can treat $\delta\Psi$ as a small perturbation

Solving EOM perturbatively

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- In this talk, we will study eom up to the second order

$$Q_B|\Psi_1\rangle = 0\,,$$

$$Q_B|\Psi_2\rangle = \frac{1}{2}\left[\Psi_1^2\right]_{S^2} + []_{D^2+\mathbb{RP}^2}\,,$$

Solving EOM perturbatively: second order

- Let's now study the second-order eom

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- Then we can find two independent equations

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$$(1-\mathbb{P})|\Psi_2\rangle = \frac{b_0^+}{L_0^+}\left[\frac{1}{2}(1-\mathbb{P})\left[\Psi_1^2\right]_{S^2} + (1-\mathbb{P})[]_{D^2+\mathbb{RP}^2}\right]$$

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- Note that b_0^+/L_0^+ corresponds to the Green's function in target space.

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- Let's study the L_0^+ nilpotent part of the second-order eom

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- After CFT gymnastics, one arrives at

$$Q_B \mathbb{P}|\Psi_2\rangle_{NSNS} = \sum_i C_i T_3 \frac{1}{\mathrm{Vol}_{X/\mathcal{I}}}(\partial c + \bar{\partial}\bar{c}) D_{gh} + \mathcal{V}\left(\frac{\partial}{\partial g_s} V_F, \frac{\partial}{\partial G^{ij}} V_F, \int H \wedge F_3 + N_{D3} - Q_{D3}\right)$$

$$Q_B \mathbb{P}|\Psi_2\rangle_{RR} = \mathcal{V}'\left(\int H \wedge F_3 + N_{D3} - Q_{D3}\right)$$

$\mathcal{V}$ and $\mathcal{V}'$ are linear combinations of derivatives of the F-term potential and the tadpole constraint

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- So, provided that the tadpole cancellation holds, and we tune the moduli such that V_F is minimized

$$Q_B \mathbb{P}|\Psi_2\rangle_{NSNS} = \sum_i C_i T_3 \frac{1}{\mathrm{Vol}_{X/\mathcal{I}}}(\partial c + \bar{\partial}\bar{c})D_{gh}\,,\ Q_B \mathbb{P}|\Psi_2\rangle_{RR} = 0$$

Solving EOM perturbatively: second order

- Hence, to show that the solution exists we need to find Ψ_2 that solves

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- And we found $\mathbb{P}|\Psi_2\rangle$

$$\begin{aligned}\frac{4\alpha'}{g_c^2}\mathbb{P}\Psi_2 = &-\frac{\pi}{18\kappa_{10}^2 g_s^2 \epsilon} c\bar{c}\Big(B_{ab}B^{ab}(\eta\bar{\partial}\bar{\xi}e^{-2\bar{\phi}} - \partial\xi\bar{\eta}e^{-2\phi}) - 2B_{ac}B^{cb}e^{-\phi}\psi^a e^{-\bar{\phi}}\bar{\psi}_b \\ &- 2i\sqrt{\frac{\alpha'}{2}} B_{ab}H^{abc}(\partial c + \bar{\partial}\bar{c})\left(e^{-\phi}\psi_c e^{-2\bar{\phi}}\bar{\partial}\bar{\xi} + e^{-\bar{\phi}}\bar{\psi}_c e^{-2\phi}\partial\xi\right)\Big).\end{aligned}$$

Conclusions

Take home messages

- String field theory provides an *easy to use* framework to study RR backgrounds.
- Provided that sugra solutions are well controlled, finding SFT counterpart isn't very difficult.
- Using the background solution in SFT, one can now compute amplitudes in RR backgrounds.

Future directions

- We are computing tree-level/one-loop amplitudes to learn how to compute amplitudes in flux backgrounds Minjae Cho, MK 24xx.xxxxx
- Generalization to Calabi-Yau orientifold compactifications?
- One can also study flux compactifications in type IIA, heterotic string theories.
- Probably there are many more exciting directions! If you are interested, let's chat!