Recent Progress on Curvature Squared Supergravities in Five and Six Dimensions

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Higher Order Curvature Terms in Supergravity

String Theory

- At low energies, superstring theory reduce to supergravity
- Superstring actions originate higher curvature terms as well as Einstein-Hilbert supergravities

Supergravity

- Inclusion of Lorentz-Chern-Simons 3-form for the cancellation of anomalies in YM and gravitational gauge currents in 10D SUGRA coupled to YM [GS]
- Modify the definition of H

$$H = dB + (AF - A^3) - (R\omega - \omega^3)$$

Higher Order Curvature Terms in Supergravity

Restore Supersymmetry

- Supersymmetric completion of LCS term is needed
- String Theory: String amplitues in tree level and one loop level
- Supergravity: Superspace methods and Noether methods
- Result: $R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}$

Problems

- Modified Lagrangian contains ghost particles [Siegel'84]
- Gauss - Bonnet combination is ghost free [Zwiebach '85]

$$e^{-1}\mathcal{L} = R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} - 4R_{\mu\nu}R^{\mu\nu} + R^2$$

- Modifications to vacuum solutions?

Solution

- String theory is **on-shell!**

Field Redefinition

- Higher curvature terms take the form of infinite series expansion as the on-shell supersymmetry works only order by order
- Only the coefficient of $R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}$ has a definite meaning
- A field redefinition is always possible
  - $g'_{\mu\nu} = g_{\mu\nu} + aR_{\mu\nu} + bg_{\mu\nu}R$
  - Can shift the coefficients of $R_{\mu\nu}R^{\mu\nu}$ and R^2 to arbitrary values

Exact Supersymmetric Models

- **Off-shell** formulations needed
- Full answer to exact supersymmetric models was achieved in $D = 4, N = 1$
- $Riem^2$ action was constructed in 5 and 6 dimensions
- $Weyl^2$ action was constructed in 5 dimensions

More Motivation

- Higher order effects in AdS/CFT
- Corrections to black hole entropy

Today's Objectives

- Off-shell Poincaré Supergavities in Five Dimensions
- All supersymmetric curvature squared invariants in Five Dimensions
- Off-shell R^2 invariant in Six Dimensions
- Brief discussion on supersymmetric $f(R)$ theory

Current Status

Status of $D = 5, \mathcal{N} = 2$ Supergravity

- Off-Shell Poincaré Supergravity
  [Bergshoeff et. al., Fujita & Ohashi, Zucker, Coomans & Ozkan]
- Off-Shell Weyl Squared Invariant
  [Hanaki, Ohashi & Tachikawa]
- Off-Shell Riemann Squared Invariant
  [Bergshoeff, Rosseel & Sezgin]

Status of $D = 6, \mathcal{N} = (1, 0)$ Supergravity

- Off-Shell Poincaré Supergravity
  [Bergshoeff, van Proeyen & Sezgin]
- Off-Shell Riemann Squared Invariant
  [Bergshoeff, Salam & Sezgin]

Superconformal Tensor Calculus

Toy Model: Proca Action from a $U(1)$ Invariant Action

Proca Action

- Proca Action

$$e^{-1}\mathcal{L}_{Proca} = -\frac{1}{4}G_{\mu\nu}G^{\mu\nu} - \frac{1}{2}m^2 C_\mu C^\mu$$

- Mass term forbids the local U(1) symmetry

U(1) Invariant Action

- Introduce a compensating scalar

$$\delta_\Lambda \sigma = m\Lambda$$

- Redefine the Proca field

$$C_\mu = A_\mu - m^{-1}\partial_\mu \sigma, \quad \delta_\Lambda A_\mu = \partial_\mu \Lambda$$

Toy Model: Proca Action from a $U(1)$ Invariant Action

U(1) Invariant Action

- U(1) invariant action

$$e^{-1}\mathcal{L}_{U(1)} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}D_\mu\sigma D^\mu\sigma \,,$$

where

$$D_\mu\sigma = \partial_\mu\sigma - mA_\mu$$

- Fix U(1) symmetry via $\sigma = 0 \rightarrow$ Proca action

Superconformal Multiplets

$\mathcal{N} = 2$, $D = 5$ Superconformal tensor calculus is based on the superconformal algebra $F^2(4)$

Generators and Gauge Fields

P_a	$e_\mu{}^a$	Translations
M_{ab}	$\omega_\mu{}^{ab}$	Rotations
D	b_μ	Dilatations
K_a	$f_a{}^\mu$	Special conformal
Λ^{ij}	$V_\mu{}^{ij}$	$SU(2)$ R-Symmetry
Q^i	ψ_μ^i	Susy
S^i	ϕ_μ^i	S-Susy

Weyl Multiplets of $\mathcal{N} = 2$ Supergravity in Five Dimensions

Conventional Constraints

$R_{\mu\nu}(P^a) = 0$	Identifies ${\omega_\mu}^{ab}$
${e^\nu}_b \widehat{R}_{\mu\nu}(M^{ab}) = 0$	Identifies ${f_\mu}^a$
$\gamma^\mu \widehat{R}^i_{\mu\nu}(Q) = 0$	Identifies ϕ^i_μ

Independent Gauge Fields

$${e_\mu}^a \quad b_\mu \quad \psi^i_\mu \quad {V_\mu}^{ij}$$

- Independent gauge fields have 21(bosonic) + 24 (fermionic) degrees of freedom. Cannot represent a superconformal multiplet

Weyl Multiplets of $\mathcal{N} = 2$ Supergravity in Five Dimensions

Additional matter fields must be added to gauge fields in order to obtain an off-shell closed multiplet

- There are two choices [Bergshoeff et al]

Standard Weyl Multiplet

$e_\mu{}^a \quad b_\mu \quad \psi^i_\mu \quad V_\mu{}^{ij} \quad T_{\mu\nu}(10) \quad D(1) \quad \chi^i(8)$

Dilaton Weyl Multiplet

$e_\mu{}^a \quad b_\mu \quad \psi^i_\mu \quad V_\mu{}^{ij} \quad B_{\mu\nu}(6) \quad C_\mu(4) \quad \sigma(1) \quad \psi^i(8)$

Construction of an off-shell Gauss - Bonnet combination requires Dilaton Weyl Multiplet

Map Between the Weyl Multiplet

$$\begin{aligned}
\chi^i &= \frac{1}{8} i\sigma^{-1} \not{D}\psi^i + \frac{1}{16} i\sigma^{-2} \not{D}\sigma\psi^i - \frac{1}{32}\sigma^{-2}\gamma\cdot G\psi^i + \cdots \\
D &= -\frac{1}{32}R + \frac{1}{8}\sigma^{-2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{16}\sigma^{-2}G_{\mu\nu}G^{\mu\nu} + \ldots \\
T_{ab} &= \frac{1}{8}\sigma^{-1}G_{ab} + \frac{1}{48}\sigma^{-2}\varepsilon_{abcde}H^{cde} + \ldots
\end{aligned}$$

Compensating Multiplets: The Vector Multiplet

Vector Multiplet

Field	Weyl Weight
A_μ	0
ρ	1
Y^{ij}	2
λ^i	$\frac{3}{2}$

- Contains a gauge field A_μ with gauge invariance $\partial_\mu \Lambda$
- Scalar is S-invariant $\delta_s \rho = 0$

Compensating Multiplets: The Linear Multiplet

Linear Multiplet

Field	Weyl Weight
L_{ij}	3
φ^i	$\frac{7}{2}$
E_a	4
N	4

- Contains a conserved current $\mathcal{D}^a E_a = 0$
- $E^a = -\frac{1}{12} e_\mu{}^a e^{-1} \varepsilon^{\mu\nu\rho\sigma\lambda} \mathcal{D}_\nu E_{\rho\sigma\lambda}$
- Invariant Action Formula: $e^{-1}\mathcal{L}_{VL} = Y_{ij} L^{ij} + \rho N + A^a E_a$

Intermezzo: How to construct off-shell actions?

Vector - Linear Action

- $e^{-1}\mathcal{L}_{VL} = Y_{ij}L^{ij} + \rho N + A^a P_a$

Embedding Formulae

- Define the elements of Vector (or Linear) multiplet in terms of other multiplets
- Use these expressions in the Vector - Linear action (or any other superconformal action) to obtain a superconformal action
- Fix the redundant superconformal symmetries

Off-Shell Poincaré Supergravity

Identify the elements of Vector Multiplet in terms of Linear Multiplet

Step 1: Composite expressions for ρ, λ_i, Y_{ij} and $\widehat{F}_{\mu\nu}$

$$
\begin{aligned}
\rho &= 2L^{-1}N + iL^{-3}L_{ij}\bar{\varphi}^i\varphi^j \\
\lambda_i &= \dots \\
Y_{ij} &= L^{-1}\Box^C L_{ij} - \mathcal{D}_a L_{k(i}\mathcal{D}^a L_{j)k}L^{km}L^{-3} - N^2 L_{ij}L^{-3} - E_\mu E^\mu L_{ij}L^{-3} \\
&\quad + \frac{8}{3}T^2 L^{-1}L_{ij} + 4L^{-1}DL_{ij} + 2E_\mu L_{k(i}\mathcal{D}^\mu L_{j)}{}^k L^{-3} + \dots \\
\widehat{F}_{\mu\nu} &= 4\mathcal{D}_{[\mu}(L^{-1}E_{\nu]}) + 2L^{-1}\widehat{R}_{\mu\nu}{}^{ij}(V)L_{ij} - 2L^{-3}L^l_k\mathcal{D}_{[\mu}L^{kp}\mathcal{D}_{\nu]}L_{lp} + \dots
\end{aligned}
$$

Construction of the Linear Multiplet Action

Construct a superconformal action

Step 2: Use $\mathcal{L}_{VL}$ to construct Linear Multiplet action

$$
\begin{aligned}
e^{-1}\mathcal{L}_L \;\; = \;\; & L^{-1}L_{ij}\Box^C L^{ij} - L^{ij}\mathcal{D}_a L_{k(i}\mathcal{D}^a L_{j)k}L^{km}L^{-3} - N^2 L^{-1} - E_\mu E^\mu L^{-1} \\
& + \frac{8}{3}LT^2 + 4DL - \frac{1}{2}L^{-3}E^{\mu\nu}L^l_k\partial_\mu L^{kp}\partial_\nu L_{pl} \\
& + 2E^{\mu\nu}\partial_\mu(L^{-1}E_\nu + V^{ij}_\nu L_{ij}L^{-1})
\end{aligned}
$$

- $L_{ij}\Box^c L^{ij} = L_{ij}\Box L^{ij}$ - $\frac{3}{8}L^2 R$
- $D = -\frac{1}{32}R + \dots$
- **Can** describe a consistent Poincaré supergravity upon gauge fixing

Construction of the Poincaré Theory

Gauge Fixing

$L_{ij} = -\frac{1}{\sqrt{2}}\delta_{ij} L$	Breaks $SU(2)$ to $U(1)_R$
$\sigma = 1$	Dilatation
$b_\mu = 0$	Conformal boost
$\psi^i = 0$	S - Supersymmetry

Off-Shell Poincaré Supergravity

$$
\begin{aligned}
e^{-1}\mathcal{L}_{LR}|_{\sigma=1} \quad = \quad & \frac{1}{2}LR - \frac{1}{4}LG_{\mu\nu}G^{\mu\nu} - \frac{1}{6}LH_{\mu\nu\rho}H^{\mu\nu\rho} - \frac{1}{2}L^{-1}\partial_\mu L\partial^\mu L \\
& + L^{-1}N^2 - L^{-1}E_\mu E^\mu + \sqrt{2}E_\mu V^\mu + LV_\mu'^{ij}V_{ij}'^{\mu}
\end{aligned}
$$

Construction of the Poincaré Theory

Remarks

- Decomposed ${V_\mu}^{ij}$ into its trace and traceless part
$$ {V_\mu}^{ij} = {V_\mu}'^{ij} + \frac{1}{\sqrt{2}} V_\mu \delta_{ij}, \qquad V_\mu'^{ij} \delta_{ij} = 0 $$
- $U(1)_R$ symmetry is gauged by the auxiliary V_μ
- Corresponding on-shell theory is the Ungauged Maxwell - Einstein theory [Gunaydin - Sierra - Townsend]

Off-Shell Higher Derivative Extensions

- Riemann Squared Invariant [Bergshoeff - Rosseel - Sezgin]
- Weyl Tensor Squared Invariant $[C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma} + \frac{1}{6}R^2]$
- Ricci Scalar Squared Invariant

Construction of the Riemann Squared Action

Riemann Squared Action - **Key Observation**

- Based on a map between the Yang - Mills multiplet and Dilaton Weyl multiplet

Riemann Squared Action - **Construction Procedure Step 1:**

- Establish a map between the Yang-Mills multiplet and Dilaton Weyl multiplet [Bergshoeff - Rosseel - Sezgin '11]

$$\left(A_\mu^I Y_I^{ij}, \lambda_I^i, \rho_I\right) \longleftrightarrow \left(\widehat{\omega}_{+\mu}^{ab}, -\widehat{V}_{ab}^{ij}, -\widehat{\psi}_{ab}^i, \widehat{G}_{ab}\right)$$

- ${\widehat{\omega}_{+\mu}}^{ab}$ is torsionful spin connection

$${\widehat{\omega}_{+\mu}}^{ab} = {\omega_\mu}^{ab} + {\widehat{H}_\mu}^{ab}$$

Construction of the Riemann Squared Action

Step 2: Construction of the Yang-Mills Action

- Linear Multiplet → Dilaton Weyl Multiplet × Yang-Mills Multiplet

$$
\begin{aligned}
L_{ij} &= \sigma Y_{ij} + \dots \\
\varphi_i &= \frac{1}{2} i\sigma \not{\mathcal{D}} \lambda_i + \dots \\
E^a &= \mathcal{D}_b(-\frac{1}{2}\sigma \widehat{F}^{ab} + \dots) - \frac{1}{8}\epsilon^{abcde} G_{bc} F_{de} \\
N &= \frac{1}{2}\rho \Box^c \sigma + \frac{1}{2}\sigma \Box^c \rho - 4\sigma\rho D + \dots
\end{aligned}
$$

- Use $\mathcal{L}_{VL}$

$$
\begin{aligned}
e^{-1}\mathcal{L}_{YM} = \; & a_{IJ}\Big(\sigma Y^I_{ij} Y^{ij\,J} - \frac{1}{4}\sigma F^I_{\mu\nu} F^{\mu\nu\,J} - \frac{1}{2}\rho^I F^J_{\mu\nu} G^{\mu\nu} - 8\sigma\rho^I F_{\mu\nu} T^{\mu\nu} \\
& + \frac{1}{2}\rho^I\rho^J \Box^C \sigma + \frac{1}{2}\sigma\rho^I \Box^C \rho^J + \frac{1}{2}\rho^I \mathcal{D}_a \rho^I \mathcal{D}^a \sigma - 4\sigma\rho^I\rho^J (D + \frac{26}{3} T^2) \\
& + 4\rho^I\rho^J G_{\mu\nu} T^{\mu\nu} - \frac{1}{8}\epsilon^{\mu\nu\rho\sigma\lambda} F^I_{\mu\nu} F^J_{\rho\sigma} C_\lambda\Big)
\end{aligned}
$$

Construction of the Riemann Squared Action

Step 3: Gauge Fix the Yang-Mills action and use the map

- Bosonic part of the Riemann tensor squared action

$$
\begin{aligned}
e^{-1}\mathcal{L}_{Riem^2} \quad = \quad & -\frac{1}{4}\Big(R_{\mu\nu ab}(\omega_+) - G_{\mu\nu}G_{ab}\Big)\Big(R^{\mu\nu ab}(\omega_+) - G^{\mu\nu}G^{ab}\Big) \\
& +\frac{1}{2}\nabla_\mu(\omega_+)G^{ab}\nabla^\mu(\omega_+)G_{ab} + V_{\mu\nu}{}^{ij}V^{\mu\nu}{}_{ij} \\
& -\frac{1}{8}\epsilon^{\mu\nu\rho\sigma\lambda}\Big(R_{\mu\nu ab}(\omega_+) - G_{\mu\nu}G_{ab}\Big)\Big(R_{\rho\sigma ab}(\omega_+) - G_{\rho\sigma}G_{ab}\Big)C_\lambda \\
& -\frac{1}{2}\epsilon^{\mu\nu\rho\sigma\lambda}B_{\rho\sigma}\Big(R_{\mu\nu ab}(\omega_+) - G_{\mu\nu}G_{ab}\Big)\Big(R_{\rho\sigma ab}(\omega_+) - G_{\rho\sigma}G_{ab}\Big)\nabla_\lambda(\omega_+)G^{ab}
\end{aligned}
$$

- $V_{\mu\nu}{}^{ij}V^{\mu\nu}{}_{ij}$ - Kinetic term for the auxiliary V_μ^{ij}
- Massive particles in the spectrum

Intermezzo

What do we know so far?

- Off-shell Poincaré supergravity in $\sigma = 1$ gauge fixing condition
- Riemann squared invariant in $\sigma = 1$ gauge fixing
  - Riemann squared term generates massive graviton
  - Auxiliary vector V_μ becomes dynamical, and generates massive dynamical auxiliary vector

Key Observation

- Massive graviton and massive auxiliary vector falls into same multiplet

Construction of Gauss-Bonnet Combination: The Idea

Key Idea

- Construct a new higher derivative invariant
- Combine two off-shell higher derivative invariants $\Rightarrow$ Vanishing ${V_{\mu\nu}}^{ij}$
- Massive multiplet decouples
- Gauss - Bonnet combination

Construction of Gauss-Bonnet Combination

Weyl Tensor Squared Invariant

- Weyl tensor square

$$C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma} = R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} - \frac{4}{3}R_{\mu\nu}R^{\mu\nu} + \frac{1}{6}R^2$$

- Gauss-Bonnet requires $C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma} + \frac{1}{6}R^2$
- In superconformal language,

$$\widehat{C}_{\mu\nu\rho\sigma}\widehat{C}^{\mu\nu\rho\sigma} + \frac{512}{3}D^2$$

- **Claim:** If the supersymmetrization of Weyl tensor square includes ${V_{\mu\nu}}^{ij}$ then it has to include $\frac{512}{3}D^2$

Construction of Gauss-Bonnet Combination

Weyl Tensor Squared Invariant

- Linear Multiplet $\rightarrow$ Dilaton Weyl Multiplet

$$
\begin{aligned}
L^{ij} &= \frac{1}{4} i \bar{\widehat{R}}^{(i}_{ab}(Q) \widehat{R}^{j)\,ab}(Q) + \frac{256}{3} i \bar{\chi}^{(i} \chi^{j)} + \frac{16}{3} \widehat{R}_{ab}{}^{ij}(V) T^{ab} \\
\varphi^i &= -\frac{1}{8} \gamma_{cd} \widehat{R}^i_{ab}(Q) \widehat{C}^{abcd} + \ldots \\
E^a &= \frac{1}{16} \epsilon_{abcde} \widehat{C}^{bcfg} \widehat{C}^{de}{}_{fg} + \ldots \\
N &= \frac{1}{8} \widehat{C}_{abcd} \widehat{C}^{abcd} + \frac{64}{3} D^2 - \frac{1}{3} \widehat{V}_{ab}{}^{ij} \widehat{V}^{ab}{}_{ij} + \ldots
\end{aligned}
$$

Construction of Gauss-Bonnet Combination

Weyl Tensor Squared Invariant

- Use $\mathcal{L}_{VL}$

$$e^{-1}\mathcal{L}_{\rho R^2} = +\frac{1}{8}\rho C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma} + \frac{64}{3}\rho D^2 - \frac{1}{3}\rho V_{ab}{}^{ij}V^{ab}{}_{ij} + \frac{1}{16}\epsilon_{abcde}A^a C^{bcfg}C^{de}{}_{fg} + \ldots$$

- Problem
  - Riemann^2 is written purely in terms of Dilaton Weyl multiplet
  - Weyl^2 uses both Dilaton Weyl multiplet and Vector multiplet
  - Need a map: Vector multiplet $\rightarrow$ Dilaton Weyl multiplet

Construction of Gauss-Bonnet Combination

Vector multiplet $\to$ Dilaton Weyl multiplet

$$\Big(A_\mu, \quad Y^{ij}, \quad \lambda^i, \quad \rho\Big) \longrightarrow \Big(C_\mu, \quad \frac{1}{4} i\sigma^{-1}\bar{\psi}^i\psi^j, \quad \psi^i, \quad \sigma\Big)$$

$$e^{-1}\mathcal{L}_{\sigma R^2}|_{\sigma=1} = +\frac{1}{8}C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma} + \frac{64}{3}D^2 - \frac{1}{3}V_{ab}{}^{ij}V^{ab}{}_{ij} + \frac{1}{16}\epsilon_{abcde}C^a C^{bcfg}C^{de}{}_{fg} + \ldots$$

Gauss-Bonnet Combination

Off-Shell Theory

$$
\begin{aligned}
e^{-1}(\mathcal{L}_{LR} + \alpha\mathcal{L}_{R^2} + \beta\mathcal{L}_{W^2}) \quad = \quad & \frac{1}{2}LR + \frac{1}{2}L^{-1}\partial_\mu L\partial^\mu L - \frac{1}{4}LG_{\mu\nu}G^{\mu\nu} + \cdots \\
& + \alpha\Big[- \frac{1}{4}R_{abcd}R^{abcd} + V_{ab}{}^{ij}V^{ab}{}_{ij} + \ldots \Big] \\
& + \beta\Big[\frac{1}{8}R_{abcd}R^{abcd} - \frac{1}{6}R_{ab}R^{ab} + \frac{1}{24}R^2 \\
& \qquad - \frac{1}{3}V_{ab}{}^{ij}V^{ab}{}_{ij} + \ldots \Big]
\end{aligned}
$$

Gauss-Bonnet Combination

Gauss-Bonnet Combination

- Set $\beta = 3\alpha$ to obtain Gauss - Bonnet combination

$$
\begin{aligned}
e^{-1}(\mathcal{L}_{LR} + \alpha \mathcal{L}_{GB}) &= \frac{1}{2} LR + \dots \\
&+ \frac{1}{8}\alpha (R_{abcd}R^{abcd} - 4R_{ab}R^{ab} + R^2 + \dots)
\end{aligned}
$$

Remarks

- No kinetic term for the auxiliary $V_\mu{}^{ij}$
- Curvature terms read the Gauss-Bonnet combination
- Corresponding on-shell theory is the Gauss-Bonnet extended Einstein-Maxwell theory

Ricci Scalar Squared Action and Off-Shell $f(R)$ Theory

Key Idea

- Define the elements of Vector (or Linear) multiplet in terms of other multiplets
- Use these expressions in the Vector - Linear action **(or any other superconformal action)** to obtain a superconformal action
- Fix the redundant superconformal symmetries

Ricci Scalar Squared Action

- Use the composite linear multiplet fields in vector multiplet action

$$\begin{aligned} Y_{ij} \; &= \; L^{-1}\Box^C L_{ij} - \mathcal{D}_a L_{k(i}\mathcal{D}^a L_{j)k} L^{km} L^{-3} - N^2 L_{ij} L^{-3} - E_\mu E^\mu L_{ij} L^{-3} \\ &\quad + \frac{8}{3} T^2 L^{-1} L_{ij} + 4L^{-1} D L_{ij} + 2E_\mu L_{k(i}\mathcal{D}^\mu L_{j)}{}^k L^{-3} + \ldots \end{aligned}$$

- $e^{-1}\mathcal{L}_{R^2} = \frac{1}{4}R^2 + (H^2)^2 + (E^2)^2 + \ldots$

Summary

Summary

	Poincaré	**Riem^2**	$Weyl^2 + R^2$	R^2	R^2_{ab}
5D	✓	✓	✓	✓	✓
6D	✓	✓	In Progress	✓	

Outlook

Outlook

- No AdS_5 solution $\rightarrow$ Gauging
- Generalize to $D = 6,\ \mathcal{N} = (1,0)$ theory, and reduction to $D = 4,\ \mathcal{N} = 2$ theory
- Higher order effects in AdS/CFT correspondence
- Corrections to black hole entropies

Thank you!