

Title: Introduction to Pure Spinor Formalism of the Superstring - Lecture 2

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Abstract: Superstring in flat and AdS<sub>5</sub>S<sup>5</sup> backgrounds

$$Q = \int^k T \rightarrow V = \int^k A_r(x, \theta)$$

SYM spinor



$$Q = \int^x D_x \rightarrow V = \int^x A_x(x, \theta)$$

SYM spinor  
gauge superfield

$$Q = \int^x D_x$$



$$Q = \int^x d_x$$



$$V = \int^x A_x(x, \theta)$$

SYM spinor gauge superfield



$$\textcircled{1} \quad \int d^4x \mathcal{L}(\psi, D_\mu \psi, F_{\mu\nu})$$

$$V = \int d^4x A_\mu(x, \theta)$$

SYM spin-1 gauge superfield

$$\int d^4x \left( A_\mu \dot{\theta}^\mu + A_m \dot{x}^m + W^a d_\mu + F^{\mu\nu} (\psi \gamma_{\mu\nu} \psi) \right)$$

↑  
Gauge current



$$Q = \int \lambda^\mu D_\mu$$

$$\uparrow$$
$$Q = \int \lambda^\mu d_\mu$$

$$= \int \lambda^\mu (p_\mu + (i\hbar)^{-1} \theta)_\mu$$

$$V = \int \lambda^\mu A_\mu(x, \theta)$$

SYM spinor gauge superfield

$$S = S_0 + \int d^4x (A_\mu \dot{\theta}^\mu + A_\mu \dot{x}^\mu + W^a d_\mu + F^{\mu\nu} (\gamma_{\mu\nu})^\alpha_\beta)$$

↑  
Lorentz current

$$Q = \int dx \mathcal{D}_x$$

$$\uparrow$$

$$Q = \int dx d_x$$

$$= \int dx (p_x + (\mathcal{P}\theta)_x)$$

$$V = \int dx A_x(x, \theta)$$

SYM spin  
gauge super

$$S = S_0 + \int dx (A_x \dot{\theta}^x + A_m \dot{x}^m + W^a d_x + F)$$

$$S_0 = \int dt (\dot{x}^m P_m + \dot{\theta}^i p_i + \dot{\lambda}^a w_a + H)$$

$$Q = \int \lambda^\mu D_\mu$$

$$\uparrow$$

$$Q = \int \lambda^\mu d_\mu$$

$$= \int \lambda^\mu (p_\mu + (\not{D}\theta)_\mu)$$

$$V = \int \lambda^\mu A_\mu(x, \theta)$$

SYM spinor gauge superfield

$$S = S_0 + \int d^4x (A_\mu \dot{\theta}^\mu + A_\mu \dot{x}^\mu + W^a d_\mu + F^{\mu\nu} (\not{D}\theta)_{\mu\nu})$$

$$S_0 = \int dt (\dot{x}^\mu p_\mu + \dot{\theta}^\mu p_\mu + \not{D}^2 + f^\mu d_\mu)$$

Lagrange current



$$Q = \int dx D_x$$

$$V = \int dx A_x(x, \theta)$$

SYM spin gauge superfield

$$Q = \int dx d_x$$

$$= \int dx (p_x + (\not{D} \theta)_x)$$

$$S = S_0 + \int dx (A_x \dot{\theta}^x + A_m \dot{x}^m + W^{\mu\nu} d_{\mu\nu} + F^{\mu\nu} (\omega \gamma_{\mu\nu} \theta))$$

$$S_0 = \int dx (\dot{x}^m p_m + \ddot{\theta}^{\mu} p_{\mu} + \cancel{\lambda} \cancel{W}_{\mu\nu} + \cancel{p}^2 + \cancel{p}_x \cancel{d}_x)$$

World Current

$$Q = \int dx D_x$$

$$Q = \int dx d_x$$

$$= \int dx (p_x + (\cancel{P} \theta)_x)$$

$$V = \int dx A_x(x, \theta)$$

SYM spinors  
gauge superfield

$$S = S_0 + \int dx (A_x \dot{\theta}^x + A_m \dot{x}^m + W^{\mu\nu} d_{\mu\nu} + F^{\mu\nu} (\omega \gamma_{\mu\nu} \psi))$$

$$S_0 = \int dx (\dot{x}^m p_m + \ddot{\theta}^{\mu} p_{\mu} + \cancel{\lambda}^{\mu} \cancel{p}_{\mu} + \cancel{P}^2 + \cancel{P}^{\mu} \cancel{d}_{\mu})$$

Grassmann  
current

$$X^m, \theta^\alpha, \hat{\theta}^\beta, \lambda^\alpha, \hat{\lambda}^\beta$$

$$p_\alpha, \hat{p}_\alpha, \psi_\alpha, \hat{\omega}_\beta$$



$x^m, \theta^x, \hat{\theta}^p, \lambda^x, \hat{\lambda}^p$   
 $p_x, \hat{p}_x, \psi_x, \hat{\omega}_p$

$$S = \int dt^2 \left( \partial x^m \bar{\partial} x_m + p_x \bar{\partial} \theta^x + \omega_x \bar{\partial} \lambda^x + \hat{p}_x \partial \hat{\theta}^x + \hat{\omega}_x \partial \hat{\lambda}^x \right)$$

$x^m, \theta^x, \hat{\theta}^p, \lambda^x, \hat{\lambda}^p$   
 $p_x, \hat{p}_x, \psi_x, \hat{\omega}_p$

$$S = \int dt dz \left( \partial x^m \bar{\partial} x_m + p_x \bar{\partial} \theta^x + \omega_x \bar{\partial} \lambda^x \right. \\ \left. + \hat{p}_x \partial \hat{\theta}^x + \hat{\omega}_x \partial \hat{\lambda}^x \right)$$

$$X^m, \theta^{\alpha}, \hat{\theta}^{\dot{\alpha}}, \lambda^{\alpha}, \hat{\lambda}^{\dot{\alpha}}$$

$$p_{\alpha}, \hat{p}_{\dot{\alpha}}, \psi_{\alpha}, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int d^2z \left( \partial X^{\mu} \bar{\partial} X_{\mu} + p_{\alpha} \bar{\partial} \theta^{\alpha} + \omega_{\alpha} \bar{\partial} \lambda^{\alpha} \right. \\ \left. + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$Q = \int d^2z \lambda^{\alpha} d_{\alpha} \quad d_{\alpha} = p_{\alpha} + \theta^{\beta} \partial_{\beta} \theta_{\alpha}, (\partial \bar{\lambda}^{\dot{\alpha}}) \psi_{\alpha}$$

$$\hat{Q} = \int d^2\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$X^m, \theta^r, \hat{\theta}^p, \lambda^r, \hat{\lambda}^p$$

$$p_r, \hat{p}_r, \psi_r, \hat{\omega}_p$$

$$S = \int dz \left( \partial X^m \bar{\partial} X_m + p_r \bar{\partial} \theta^r + w_r \bar{\partial} \lambda^r + \hat{p}_r \partial \hat{\theta}^r + \hat{\omega}_r \partial \hat{\lambda}^r \right)$$

$$Q = \int dz \lambda^r d_r$$

$$d_r = p_r + \theta^k \theta_l \cdot (\partial \bar{\lambda}^k \partial \lambda_l)$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^r \hat{d}_r$$

$$d_r(z) = \frac{1}{y-z} \pi^r \gamma_{r-p}$$

$$\pi^r = \partial X^r + \theta \gamma^r \partial \theta$$

$$Q = \int \lambda^\kappa D_\kappa$$

$$Q = \int \lambda^\kappa d_\kappa$$

$$= \int \lambda^\kappa (p_\kappa + (\cancel{P} \theta)_\kappa)$$

$$V = \int \lambda^\kappa A_\kappa(x, \theta)$$

SYM spinor  
gauge superfield

$$S = S_0 + \int d^4x (A_\kappa \dot{\theta}^\kappa + A_m \dot{x}^m + W^a d_\kappa + F^{mn} (\omega \gamma_{mn}))$$

$$S_0 = \int dt (\dot{x}^m p_m + \dot{\theta}^{\dot{\alpha}} p_{\dot{\alpha}} + \lambda^r \dot{u}_r$$

$$+ \cancel{P}^2 + \cancel{P}^r \cancel{V}_r)$$

U(1) current



$$x^n, \theta^n, \hat{\theta}^p, \lambda^n, \hat{\lambda}^p$$

$$p_n, \hat{p}_p, \psi_n, \hat{\omega}_p$$

$$S = \int dz \left( \partial x^n \bar{\partial} x_n + p_n \bar{\partial} \theta^n + \omega_n \bar{\partial} \lambda^n + \hat{p}_n \partial \hat{\theta}^n + \hat{\omega}_n \partial \hat{\lambda}^n \right)$$

$$Q = \int dz \quad d_n = p_n \theta \dot{\theta}, (\theta \ddot{x}) \dot{x}$$

$$\hat{Q} = \int dz \quad \frac{d(\hat{\lambda})}{d\hat{p}}(z) \rightarrow \frac{1}{y-z} \pi^m \gamma_{m-p}$$

$$\pi^m = \partial x^m + \theta \gamma^m \partial \theta$$

$$X^\mu, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\mu, \hat{\lambda}^{\dot{\mu}}$$

$$p_\mu, \hat{p}_\mu, \psi_\alpha, \hat{\omega}_\alpha$$

$$S = \int d^2z \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{\omega}_\alpha \partial \hat{\lambda}^\alpha \right)$$

$$Q = \int d^2z \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta / z, (\theta^\beta \partial \theta) / z$$

$$\hat{Q} = \int d^2\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$\hat{d}_{\dot{\alpha}} = \hat{p}_{\dot{\alpha}} + \hat{\theta}^{\dot{\beta}} \hat{\theta}_{\dot{\beta}} / \bar{z}, (\hat{\theta}^{\dot{\beta}} \partial \hat{\theta}) / \bar{z}$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$\pi^\mu = \partial X^\mu + \theta^\alpha \partial \theta^\alpha$$

massless

massive

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int d^2z \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta / z, (\theta^\beta \bar{\partial} \theta) \chi_\alpha / z$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$d_{\dot{\alpha}} = \hat{p}_{\dot{\alpha}} + \hat{\theta}^{\dot{\beta}} \hat{\theta}_{\dot{\beta}} / \bar{z}, (\hat{\theta}^{\dot{\beta}} \bar{\partial} \hat{\theta}) \hat{\chi}_{\dot{\alpha}} / \bar{z}$$

$$\pi^\mu = \partial X^\mu + \theta \chi^\mu \bar{\partial} \theta$$

Open string

massless

massive

$$\chi_\alpha + \pi^\mu A_{\mu\alpha} + \lambda^\beta A_{\beta\alpha} + (\omega \chi_{\dot{\alpha}}) A_{\dot{\alpha}\alpha} + \partial \lambda^{\dot{\beta}} A_{\dot{\beta}\alpha}$$

$$x^m, \theta^r, \hat{\theta}^p, \lambda^s, \hat{\lambda}^q$$

$$p_\alpha, \hat{p}_\alpha, \psi_\alpha, \hat{\omega}_\alpha$$

$$S = \int d^2z \left( \partial x^\alpha \bar{\partial} x_\alpha + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{\omega}_\alpha \partial \hat{\lambda}^\alpha \right)$$

$$Q = \int d^2z \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta / 2, (\theta^\beta \bar{\partial} \theta) \chi_\alpha \theta_\beta$$

$$\hat{Q} = \int d^2z \hat{\lambda}^\alpha \hat{d}_\alpha$$

$$d_\alpha(z) d_\beta(z) = \frac{1}{y-z} \pi^\gamma \chi_{\alpha\beta\gamma}$$

$$\pi^\alpha = \partial x^\alpha + \theta \chi^\alpha \partial \theta$$

Open

$$A_\alpha(x, \theta)$$

$$\left( \partial \theta^\alpha A_{\alpha\beta} + \pi^\alpha A_{\alpha m} + d_\gamma A_\alpha^\gamma + (\omega \chi_{\alpha\beta}) A_{\alpha\beta} \right) + \partial \lambda^\alpha A_\alpha$$

massless

massive

$$x^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_\alpha, \psi_\alpha, \hat{\omega}_\alpha$$

$$S = \int d^2z \left( \partial x^\mu \bar{\partial} x_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{\omega}_\alpha \partial \hat{\lambda}^\alpha \right)$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \chi_{\beta\alpha}, (\theta^\beta \dot{\chi}_{\beta\alpha}) \chi_{\gamma\alpha}$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^\alpha \hat{d}_\alpha$$

$$\hat{d}_\alpha(z) = \frac{1}{y-z} \Pi^\alpha \chi_{\alpha\beta}$$

$$\Pi^\alpha = \partial x^\alpha + \theta^\beta \chi^\alpha_\beta \partial \theta$$

string

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$V = \lambda^\alpha \left( \partial \theta^\beta A_{\beta\gamma} + \Pi^\alpha A_{\alpha\gamma} + d_\gamma A_\alpha^\gamma + (\omega_{\alpha\beta} \lambda^\beta) A_\alpha^\gamma \right) + \partial \lambda^\alpha A_\alpha$$

$$x^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int d^2z \left( \partial x^\mu \bar{\partial} x_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta d_\alpha + (\theta^\beta \partial_\beta \theta^\gamma) \theta_\alpha d_\gamma$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$d_{\dot{\alpha}}(\bar{z}) = \frac{1}{y-z} \pi^{\dot{\alpha}} \gamma_{m-p}$$

$$\pi^{\dot{\alpha}} = \partial x^\mu + \theta \gamma^\mu \partial \theta$$

string

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$V = \left( \partial \theta^{\dot{\alpha}} A_{\dot{\alpha}} + \pi^{\dot{\alpha}} A_{\dot{\alpha}} + d_{\dot{\alpha}} A_{\dot{\alpha}} + (\omega \gamma_{\dot{\alpha}}) A_{\dot{\alpha}} \right) + \partial \lambda^{\dot{\alpha}} A_{\dot{\alpha}}$$

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\mu, \hat{p}_\mu, \psi_\mu, \hat{\psi}_\mu$$

$$S = \int d^2z \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_\alpha \partial \hat{\theta}^\alpha + \hat{\omega}_\alpha \partial \hat{\lambda}^\alpha \right)$$

$$\omega_\mu$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta \gamma_\alpha, (\theta^\beta \gamma_\beta \theta^\alpha)$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$d_{\dot{\alpha}} = \hat{p}_{\dot{\alpha}} + \hat{\theta}^{\dot{\beta}} \hat{\theta}_{\dot{\beta}} \hat{\gamma}_{\dot{\alpha}}, (\hat{\theta}^{\dot{\beta}} \hat{\gamma}_{\dot{\beta}} \hat{\theta}^{\dot{\alpha}})$$

Open string

massless  $V = \lambda^\alpha A_\alpha(x, \theta)$

$$d_{\dot{\alpha}} d_{\dot{\beta}}(z) = \frac{1}{y-z} \Pi^{\dot{\alpha}\dot{\beta}} \gamma_{\dot{\alpha}\dot{\beta}} + \dots$$

$$\Pi^{\dot{\alpha}\dot{\beta}} = \partial X^{\dot{\alpha}} \cdot \theta \gamma^{\dot{\beta}} \partial \theta$$

massive  $V = \lambda^\alpha \left( \partial \theta^\beta A_{\dot{\beta}}^{(\alpha)} + \Pi^{\dot{\alpha}\dot{\beta}} A_{\dot{\alpha}\dot{\beta}} + d_{\dot{\gamma}} A_{\dot{\gamma}}^\alpha + (\omega_{\dot{\gamma}\dot{\delta}}) A_{\dot{\gamma}\dot{\delta}}^\alpha \right) + \partial \lambda^{\dot{\alpha}} A_{\dot{\alpha}}$

$$Q = \int d^3x \mathcal{D}_k$$

$$V = \int d^3x A_\mu(x, \theta)$$

SYM spin-1  
gauge superfield

$$S = S_0 + \int d^4x (A_\mu \dot{\theta}^\mu + A_m \dot{x}^m + W^a d_\mu + F^{mn} (\gamma_{mn})^\mu)$$

$$S_0 = \int dt (\dot{x}^m P_m + \dot{\theta}^a P_a + \dot{\lambda}^i W_i$$

$$+ \dot{P}^2 + \dots)$$

↑  
Lorentz current

$$(\dots)$$



$$Q = \int dx \mathcal{D}_x$$

$$\uparrow$$

$$Q = \int dx \mathcal{D}_x$$

$$= \int dx (p_x + (\cancel{\mathcal{P}} \theta)_x)$$

$$\lambda \gamma^m \lambda = 0$$

$$V = \int dx A_x(x, \theta)$$

SYM spinor gauge superfield

$$S = S_0 + \int dx (A_x \dot{\theta}^x + A_m \dot{x}^m + W^a d_x + F^{mn} (\omega \gamma_{mn}))$$

$$S_0 = \int dx (\dot{x}^m p_m + \dot{\theta}^a p_a + \lambda \dot{w}_x$$

$$+ \cancel{\mathcal{P}^2} + \cancel{\mathcal{P}_x \lambda})$$

$$S_{\omega} = \int dx (\gamma^m \lambda)_a \rightarrow (\omega \gamma^m \lambda)_a, \omega \lambda_x$$

ghost current

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\psi}_{\dot{\alpha}}$$

$$S = \int dz \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$\omega_\alpha$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \chi_{\beta\alpha} + (\theta^{\dot{\beta}} \dot{\chi}_{\beta\alpha})$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$\hat{d}_{\dot{\alpha}} = \hat{p}_{\dot{\alpha}} + \theta^{\beta\dot{\gamma}} \chi_{\beta\dot{\gamma}\dot{\alpha}} + (\theta^{\beta\dot{\gamma}} \dot{\chi}_{\beta\dot{\gamma}\dot{\alpha}})$$

Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$+ (\omega \lambda) A_\omega$$

$$\pi^{\alpha\dot{\beta}} = \partial X^\alpha + \theta^{\beta\dot{\gamma}} \chi_{\beta\dot{\gamma}\alpha}$$

massive

$$V = \lambda^\alpha \left( \partial \theta^{\dot{\beta}} A_{\dot{\beta}\alpha}^{(p)} + \pi^{\alpha\dot{\beta}} A_{\dot{\beta}\alpha} + d_{\dot{\gamma}} A_{\dot{\gamma}\alpha}^{\dot{\gamma}} + (\omega \chi_{\dot{\gamma}\alpha}) A_{\dot{\gamma}\alpha}^{\dot{\gamma}} \right) + \partial \lambda^{\dot{\alpha}} \tilde{A}_{\dot{\alpha}}$$

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int d^2z \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$\omega_\alpha$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \chi_{\beta\alpha}, (\theta^{\dot{\beta}} \dot{\chi}_{\dot{\beta}\alpha})$$

Open string

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$d_{\dot{\alpha}}(z) d_{\dot{\beta}}(\bar{z}) = \frac{1}{y-z} \pi^{\dot{\alpha}\dot{\beta}} \chi_{\dot{\alpha}\dot{\beta}}$$

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$+ (\omega_\alpha) A_\alpha$$

$$\pi^{\dot{\alpha}\dot{\beta}} = \partial X^\mu + \theta^\nu \partial \theta$$

massive

$$V = \lambda^\alpha \left( \partial \theta^{\dot{\beta}} A_{\dot{\beta}\alpha}^{(p)} + \pi^{\dot{\alpha}\dot{\beta}} A_{\dot{\alpha}\dot{\beta}\alpha} + d_{\dot{\gamma}} A_{\dot{\gamma}\alpha}^{\dot{\gamma}} + (\omega_{\dot{\gamma}\dot{\alpha}}) A_{\dot{\gamma}\alpha}^{\dot{\gamma}} \right) + \partial \lambda^{\dot{\alpha}} \tilde{A}_{\dot{\alpha}}, \quad QV = 0 +$$

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int dz \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$\omega_\alpha$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta \gamma_\alpha \cdot (\theta)$$

Open string

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$d_{\dot{\alpha}}(z) d_{\dot{\beta}}(\bar{z}) = \frac{1}{y-z} \Pi^{\dot{\alpha}\dot{\beta}} \gamma_{m-p}$$

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$+ (\omega \lambda) A_\alpha$$

$$\Pi^{\dot{\alpha}\dot{\beta}} = \partial X^\mu + \theta \gamma^\mu \partial \theta$$

massive

$$V = \lambda^\alpha \left( \partial \theta^\beta A_{\dot{\beta}}^{(\alpha)} + \Pi^{\dot{\alpha}\dot{\beta}} A_{\dot{\alpha}\dot{\beta}} + d_\gamma A_\alpha^\gamma + (\omega \gamma_{\dot{\alpha}\dot{\beta}}) A_{\dot{\alpha}\dot{\beta}} \right) + \partial \lambda^{\dot{\alpha}} \tilde{A}_{\dot{\alpha}}, \quad QV=0 \rightarrow \text{massive spin } \frac{1}{2} \text{ multiplet}$$

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int d^2z \left( \partial X^\mu \bar{\partial} X_\mu + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$$\omega_\alpha$$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \chi_{\beta\alpha}, (\theta^{\dot{\beta}} \dot{\chi}_{\dot{\beta}\alpha})$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$\hat{d}_{\dot{\alpha}} = \hat{p}_{\dot{\alpha}} + \theta^{\beta} \chi_{\beta\dot{\alpha}}, (\theta^{\dot{\beta}} \dot{\chi}_{\dot{\beta}\dot{\alpha}})$$

open string

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$+ (\omega_\alpha) A_\alpha$$

$$\pi^{\dot{\alpha}\alpha} = \partial X^\alpha + \theta^\beta \chi_{\beta\alpha}$$

$$V = \lambda^\alpha \left( \partial \theta^{\dot{\beta}} A_{\dot{\beta}\alpha}^{(\dot{\beta})} + \pi^{\dot{\alpha}\alpha} A_{\dot{\alpha}\alpha} + d_\gamma A_\alpha^\gamma + (\omega_{\dot{\gamma}\alpha}) A_{\dot{\gamma}\alpha} \right) + \partial \lambda^{\dot{\alpha}} \tilde{A}_{\dot{\alpha}}, \quad QV = 0 \rightarrow \text{massive spin 2 multiplet}$$

Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

massive

$$V = \lambda^\alpha \left( \partial \theta^\mu A_{\mu\alpha}^{(p)} + \pi^\alpha A_{\alpha m} + d_\gamma A_\gamma^\alpha + (\partial \gamma_\mu A_\mu^\alpha) + \partial \lambda^\mu \tilde{A}_\mu \right), \quad QV=0 \rightarrow \text{massive spin } \frac{1}{2} \text{ multiplet}$$

$$Q = \int d\bar{z} \left( \hat{A}^\alpha \hat{d}_\alpha + (\omega \lambda) \right)$$

$$d_{\mu\alpha}^{(p)} d_{\nu\beta}^{(z)} \rightarrow \frac{1}{y-z} \pi^\alpha \gamma_{\mu\nu\alpha\beta}$$

$$\pi^\alpha = \partial X^\alpha + \theta \gamma^\alpha \partial \theta$$

Close d

$$V = \lambda^\alpha \hat{\lambda}^\mu \hat{A}_{\mu\alpha}$$

Open string

massless

$$V = \lambda^{\mu} A_{\mu}(x, \theta)$$

massive

$$V = \lambda^{\mu} \left( \partial \theta^{\rho} A_{\mu\rho}^{(2)} + \pi^{\mu\nu} A_{\nu m} + d_{\nu} A_{\nu}^{\gamma} + (\partial \gamma_{\mu\nu}) A_{\nu}^{\mu} \right) + \partial \lambda^{\mu} \tilde{A}_{\mu}, \quad QV = 0 \rightarrow \text{massive spin 2 multiplet}$$

$$Q = \int d\bar{\sigma} \left( \hat{A}^{\mu} \hat{d}_{\mu} + (\omega \lambda) \right)$$

$$d_{\mu}^{\nu} d_{\rho}^{\sigma} \rightarrow \frac{1}{y-z} \pi^{\nu} \gamma_{\mu\rho\sigma}$$

$$\pi^{\mu\nu} = \partial X^{\mu} + \theta \gamma^{\mu\nu} \partial \theta$$

Closed

$$V = \lambda^{\mu} \hat{\lambda}^{\rho} A_{\mu\rho}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$



Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

massive

$$V = \lambda^\alpha \left( \partial \theta^\mu A_{\mu\alpha}^{(0)} + \pi^\mu A_{\mu\alpha} + d_\gamma A_{\alpha\gamma} + (\partial \gamma_\mu A_{\alpha\mu}) + \partial \lambda^\mu \tilde{A}_\mu \right), QV = 0 \rightarrow \text{massive spin } \frac{1}{2} \text{ multiplet}$$

$$Q = \int d\bar{z} \left( \hat{A}^\alpha \hat{d}_\alpha + (\omega \lambda) \right)$$

$$d_{\mu\alpha}^{(0)} d_{\nu\beta}^{(0)} \rightarrow \frac{1}{y-z} \pi^\gamma \gamma_{\mu\nu\alpha\beta}$$

$$\pi^\mu = \partial X^\mu + \theta \gamma^\mu \partial \theta$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\mu A_{\mu\alpha}(x, \theta, \hat{\theta}) \rightarrow \lambda^\alpha A_\alpha$$

$$QV = \hat{Q}V = 0$$



Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

massive

$$V = \lambda^\alpha \left( \partial \theta^\mu A_{\mu\alpha}^{(p)} + \pi^\alpha A_{\alpha m} + d_\gamma A_{\alpha\gamma} + (\partial \gamma_\mu A_{\mu\alpha}^{(p)}) + \partial \lambda^\mu \tilde{A}_\mu \right), QV = 0 \rightarrow \text{massive spin } \frac{1}{2} \text{ multiplet}$$

$$Q = \int d\bar{z} \left( \hat{A}^\alpha \hat{d}_\alpha + (\omega) \right)$$

$$d_{\mu\alpha}^{(p)} d_{\mu\alpha}^{(p)} \rightarrow \frac{1}{y-z} \pi^\alpha \gamma_{\mu\alpha}$$

$$\pi^\alpha = \partial X^\alpha + \theta \gamma^\alpha \partial \theta$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\mu A_{\mu\alpha}(x, \theta, \hat{\theta})$$

$$\rightarrow \lambda^\alpha \hat{\lambda}^\mu (A_{\mu\alpha} \times \hat{A}_\mu)$$

$$QV = \hat{Q}V = 0$$

$$A_\alpha(x, \theta) = a_m (\gamma^m \theta)_\alpha + (\theta \gamma^{\mu\nu} \theta) (\gamma_{\mu\nu} \chi)_\alpha + \dots$$

$$Q = \lambda^\alpha D_\alpha$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spin gauge superfield

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{V} \theta)_\alpha)$$

$$0 = \not{V} \theta$$

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^{\mu\nu} d_{\mu\nu} + F^{\mu\nu} (\omega \gamma_{\mu\nu} \theta))$$

$$S_0 = \int dt (\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \dot{\lambda}^\alpha w_\alpha + \dot{\lambda}^\alpha p_\alpha^2 + \dots)$$

Weyle current

$$S w_\alpha = \lambda^\alpha (\gamma^m \lambda)_\alpha \rightarrow (\omega \gamma^{\mu\nu} \lambda)_\alpha, \omega \lambda^\alpha$$

Closed

$$V = \lambda^\kappa \hat{\lambda}^\beta A_{\kappa\beta}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^\kappa \hat{\lambda}^\beta (A_{\kappa\beta} \hat{A}_p)$$

$$= \lambda^\kappa \hat{\lambda}^\beta (a_m \hat{a}_n (\gamma^m \theta)_\kappa (\gamma^n \hat{\theta})_\beta)_p$$

Closed

$$V = \lambda^x \hat{\lambda}^p A_{x,p}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^x \hat{\lambda}^p (A_{x,p} \hat{x} \hat{A}_p)$$

$$= \lambda^x \hat{\lambda}^p (a_m \hat{a}_m (\gamma^x \theta)_p (\gamma^x \hat{\theta})_p$$

$$a_m \hat{\chi}^x (\gamma^x \theta)_p (\gamma^x \theta)_p (\gamma^x \theta)_p$$

$$+ \chi a_m$$

$$+ \chi \hat{\chi}$$

$$A_\alpha(x, \theta) = a_m (\gamma^m \theta)_\alpha + (\gamma_n \theta)_\alpha (\chi \gamma^m \theta) + \dots$$

$$Q = \lambda^\alpha D_\alpha$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spin gauge superfield

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{V} \theta)_\alpha)$$

$$\lambda \gamma^m \lambda = 0$$

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^\alpha d_\alpha + F^{mn} (\omega \gamma_{mn} \mathbb{1}))$$

$$S_0 = \int d\tau (\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \dot{\lambda}^r W_r$$

$$+ \delta P^2 + \cancel{(\not{V} \lambda)_\alpha})$$

create current

$$\delta W_\alpha = \cancel{(\not{V} \lambda)_\alpha} \rightarrow (\omega \gamma^m \lambda)_\alpha, \omega \lambda^\alpha$$

Closed

$$V = \lambda^\kappa \hat{\lambda}^\rho A_{\kappa\rho}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^\kappa \hat{\lambda}^\rho (A_{\kappa\rho} \hat{x} \hat{A}_\rho)$$

$$= \lambda^\kappa \hat{\lambda}^\rho \left( a_m \hat{a}_n (\gamma^\theta)_\kappa (\gamma^\theta)_\rho \right. \\ \left. a_m \hat{\lambda}^\gamma (\gamma^\theta)_\kappa (\gamma^\theta)_\rho \right)$$

$$= \lambda^\kappa \hat{\lambda}^\rho (g_{\kappa\rho} + b_{\kappa\rho} + \gamma_{\kappa\rho} \psi)$$

$$+ \chi a_m \\ + \chi \hat{\lambda}$$

Closed

$$V = \lambda^{\kappa} \hat{\lambda}^{\rho} A_{\kappa\rho}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^{\kappa} \hat{\lambda}^{\rho} (A_{\kappa\rho}(x) \times \hat{A}_{\rho}(x))$$

$$= \lambda^{\kappa} \hat{\lambda}^{\rho} (a_m \hat{a}_n (\gamma^{\kappa} \theta)_{\rho} (\gamma^{\rho} \hat{\theta})_{\rho})$$

$$a_m \hat{\lambda}^{\rho} (\gamma^{\kappa} \theta)_{\rho} (\gamma^{\rho} \hat{\theta})_{\rho}$$

$$= \lambda^{\kappa} \hat{\lambda}^{\rho} \sqrt{(g_{\kappa n} + b_{\kappa n} + \gamma_{\kappa n} \varphi)} (\gamma^{\kappa} \theta)_{\rho} (\gamma^{\rho} \hat{\theta})_{\rho}$$

Closed

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^\alpha \hat{\lambda}^\beta (A_{\alpha\beta}(x) \times \hat{A}_P(x))$$

$$= \lambda^\alpha \hat{\lambda}^\beta (a_m \hat{a}_n (\gamma^\theta)_\alpha (\gamma^\theta)_\beta)$$

$$a_m \hat{\lambda}^\gamma (\gamma^\theta)_\alpha (\gamma^\theta)_\beta (\gamma^\theta)_\gamma + \lambda \hat{a} + \lambda \hat{\lambda}$$

$$= \lambda^\alpha \hat{\lambda}^\beta \left[ (g_{\alpha\beta} + b_{\alpha\beta} + \gamma_{\alpha\beta} \psi) (\gamma^\theta)_\alpha (\gamma^\theta)_\beta + \psi_{\alpha\beta} (\gamma^\theta)_\alpha (\gamma^\theta)_\beta + \hat{\psi} \right]$$



Closed

$$V = \lambda^x \hat{\lambda}^p A_{xp}(\chi, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^x \hat{\lambda}^p (A(x)^x \hat{A}_p(x))$$

$$= \lambda^x \hat{\lambda}^p (a_m \hat{a}_n (\chi^m \theta)_x (\chi^n \hat{\theta})_p)$$

$$a_m \hat{\chi}^r (\chi^m \theta)_x (\chi^n \hat{\theta})_y (\chi^p \hat{\theta})_z + \dots$$

$$= \lambda^x \hat{\lambda}^p \left[ (g_{mn} + b_{mn} + \gamma_m \psi) (\chi^m \theta)_x (\chi^n \hat{\theta})_p + \psi_n^\delta (\chi^m \theta)_x (\chi^n \hat{\theta})_y (\chi^p \hat{\theta})_z + \hat{\psi} + F^{\delta j} (\theta^j) (\hat{\theta}^k) \right]$$

$$V = \lambda (\partial_\mu A_\nu^m + \Pi^m A_{\nu\mu} + d_\nu A_\mu^m + (b_{\nu\mu}^m) A_\nu^m) + \partial \lambda^{\hat{p}} \tilde{A}_1, \quad QV=0 \rightarrow \text{massive spin 2 multiplet}$$

Closed

$$V = \lambda^{\hat{x}} \hat{\lambda}^{\hat{p}} A_{\mu\nu p}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^{\hat{x}} \hat{\lambda}^{\hat{p}} (A_{\mu\nu p}^{\hat{x}} \hat{A}_{\hat{p}}^{\hat{x}})$$

$$= \lambda^{\hat{x}} \hat{\lambda}^{\hat{p}} (a_m \hat{a}_m (\gamma^\mu \theta)_\nu (\gamma^\nu \hat{\theta})_\rho$$

$$a_m \hat{\chi}^{\hat{x}} (\gamma^\mu \theta)_\nu (\gamma^\nu \hat{\theta})_\rho (\gamma^\rho \hat{\theta})_{\hat{p}} + \dots)$$

$$= \lambda^{\hat{x}} \hat{\lambda}^{\hat{p}} \left( (g_{\mu\nu} + b_{\mu\nu} + \gamma_{\mu\nu} \varphi) (\gamma^\mu \theta)_\nu (\gamma^\nu \hat{\theta})_\rho + \chi \hat{a} + \chi \hat{\chi} \right. \\ \left. + \psi_n^{\hat{\delta}} (\gamma^\mu \theta)_\nu (\gamma^\nu \hat{\theta})_\rho (\gamma^\rho \hat{\theta})_{\hat{p}} + \hat{\Psi} + F^{\hat{x}\hat{p}} (\theta^{\hat{x}})_{\hat{p}} (\hat{\theta}^{\hat{p}})_{\hat{x}} \right)$$

$$Q = \lambda^{\alpha} T$$

$$V = \lambda^{\alpha} A_{\alpha}(x, \theta)$$

SYM spin gauge superfield

$$S = S_0 + \int dt (A_{\alpha} \dot{\theta}^{\alpha} + A_m \dot{x}^m + W^{\alpha} d_{\alpha} + F^{mn} (\omega \gamma_{mn} \lambda))$$

$$Q = \lambda^{\alpha} T$$

$$= \lambda^{\alpha} (\dots)$$

$$S_0 = \int dt (\dot{x}^m P_m + \dot{\theta}^{\alpha} p_{\alpha} + \lambda^{\alpha} W_{\alpha} + P^{\alpha} + \dots)$$

ghost current

$$S W_{\alpha} = (\lambda^{\alpha} \gamma^m \lambda)_{\alpha} \rightarrow (\omega \gamma^m \lambda), \omega \lambda^{\alpha}$$

$$A_\alpha(x, \theta) = a_m (\gamma^m \theta)_\alpha + (\gamma_\alpha \theta)_m (\gamma^\mu \theta)_\mu + \dots$$

$$Q = \lambda^\alpha D_\alpha$$

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{\partial} \theta)_\alpha)$$

$$\lambda \gamma^\mu \lambda = 0$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spinor gauge superfield

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^2 d_\alpha + F^{\mu\nu} (\omega \gamma_{\mu\nu})_\alpha)$$

$$S_0 = \int dt (\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \lambda^\alpha \omega_\alpha$$

$$+ \not{P}^2 + \not{P} \not{K})$$

logarithmic current

$$S \omega_\alpha = \Lambda_\alpha (\gamma^\mu \lambda)_\alpha \rightarrow (\omega \gamma^\mu \lambda)_\alpha, \omega_\alpha \lambda^\alpha$$

$$S = S_0 + \int dz d\bar{z} \left( G_{MN} + B_{MN} \right)$$

$M = m, \alpha, \hat{2}$

$$Q = \lambda^\alpha D_\alpha$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spinors  
gauge superfield

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{D}\theta)_\alpha)$$

$$\not{D}\theta = 0$$

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^m d_\alpha + F^{mn} (\omega \gamma_{mn})^\alpha)$$

$$S_0 = \int d\tau (\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \lambda W_\alpha$$

$$+ \cancel{P^2} + \cancel{(\not{D}\theta)_\alpha})$$

Gravitational current

$$\delta W_\alpha = \Lambda_\alpha (\gamma^m \lambda)_\alpha \rightarrow (\omega \gamma^m \lambda), \omega_\alpha \lambda^\alpha$$

$$S = S_0 + \int dz d\bar{z} \left( G_{MN}(x, \theta) + B_{MN}(x, \theta) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{2}$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^2)$$

$$Q = \lambda^\alpha D_\alpha$$

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{D}\theta)_\alpha)$$

$$\not{D}\theta = 0$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spin<sub>1/2</sub>  
gauge superfield

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^m d_\alpha + F^{mn} (\omega \gamma_{mn})^\alpha)$$

$$S_0 = \int d\tau (\dot{x}^m P_m + \dot{\theta}^\alpha p_\alpha + \lambda W_\alpha$$

$$+ \cancel{P^2} + \cancel{(\not{D}\theta)_\alpha})$$

Gravitational current

$$\delta W_\alpha = \cancel{\Lambda_\alpha (\gamma^m \lambda)_\alpha} \rightarrow (\omega \gamma^m \lambda)_\alpha, \omega_\alpha^\beta \lambda^\gamma$$



$$S = S_0 + \int d^2z d\bar{z} \left( G_{MN}(x, \theta) + B_{MN}(x, \theta) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{2} \quad + \quad E_M^{\hat{2}} \partial Y^M \hat{d}_2 + E_M^{\alpha} d_\alpha \bar{\partial} Y^M$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^2)$$

$$Q = \lambda^\kappa D_\kappa$$

$$Q = \lambda^\kappa d_\kappa$$

$$= \lambda^\kappa (p_\kappa + (\nabla \Theta)_\kappa)$$

$$\lambda \gamma^m \lambda = 0$$

$$V = \lambda^\kappa A_\kappa(x, \theta)$$

SYM spin gauge superfield

$$S = S_0 + \int d^4x (A_\kappa \dot{\theta}^\kappa + A_m \dot{x}^m + W^m d_\kappa + F^{mn} (\omega \gamma_{mn})^\kappa)$$

$$S_0 = \int d\tau (\dot{x}^m p_m + \dot{\theta}^\kappa p_\kappa + \lambda \dot{w}_\kappa$$

$$+ p^2 + \cancel{(\cancel{p_\kappa} \cancel{d_\kappa})})$$

locate current

$$\delta w_\kappa = \cancel{\Lambda_\kappa (\gamma^m \lambda)_\alpha} \rightarrow (\omega \gamma^m \lambda)_\kappa, \omega_\kappa \lambda^\kappa$$

$$S = S_0 + \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{\alpha} \quad + \quad E_M^{\hat{\alpha}} \partial Y^M \hat{d}_{\hat{\alpha}} + E_M^{\alpha} d_{\alpha} \bar{\partial} Y^M$$

$$Y^M = (x^m, \theta^{\alpha}, \hat{\theta}^{\hat{\alpha}}) \quad + \quad F^{\hat{\alpha}\beta} (x, \theta, \hat{\theta}) d_{\alpha} \hat{d}_{\hat{\alpha}}$$

$$\begin{aligned}
S = S_0 + \int dz d\bar{z} & \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N \\
M = m, \alpha, \hat{2} & + E_M^{\hat{2}} \partial Y^M \hat{d}_2 + E_M^{\alpha} d_\alpha \bar{\partial} Y^M \\
Y^M = (x^m, \theta^\alpha, \hat{\theta}^2) & + F^{\hat{2}\alpha} (x, \theta, \hat{\theta}) d_\alpha \hat{d}_2 \\
& + \Omega_M^{ab} \partial Y^M (\hat{\omega}_{ab}, \hat{\lambda}) + \hat{\Omega}_M^{ab} (\omega_{ab}, \lambda) \bar{\partial} Y^M \\
& + \Omega^{\alpha ab} d_\alpha (\hat{\omega}_{ab}, \hat{\lambda}) + \Omega^{\alpha\beta} (\omega_{ab}, \lambda) \hat{d}_2 + R^{abcd} (\omega_{ab}, \lambda) (\hat{\omega}_{cd}, \hat{\lambda})
\end{aligned}$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{closed}} = \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{2}$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^2)$$

$$+ \left( E_M^{\alpha} \right) \partial Y^M \hat{d}_\alpha + \left( E_M^{\hat{2}} \right) d_x \bar{\partial}$$

$$+ F^{\alpha\beta}(x, \theta, \hat{\theta}) d_\alpha \hat{d}_\beta$$

$$+ \Omega_M^{ab} \partial Y^M (\hat{\omega}_{ab}) + \hat{\Omega}_M^{ab} (\omega_{ab})$$

$$+ \Omega_{\alpha\beta} d_x (\hat{\omega}_{\alpha\beta}) + \Omega^{\alpha\beta} (\omega_{\alpha\beta}) \hat{d}_x + R^{ab\hat{c}\hat{d}} (\omega_{\hat{c}\hat{d}})$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{closed}} = \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{\alpha}$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$$

$$+ \left( E_M^{\alpha} \right) \partial Y^M \hat{d}_\alpha + \left( E_M^{\hat{\alpha}} \right) d_\alpha \bar{\partial} Y^M$$

$$+ F^{\alpha\beta}(x, \theta, \hat{\theta}) d_\alpha \hat{d}_\beta$$

$$+ \Omega_M^{\alpha\beta} \partial Y^M (\hat{\omega}_{\alpha\beta}) + \hat{\Omega}_M^{\alpha\beta} (\omega_{\alpha\beta}) \bar{\partial} Y^M$$

$$+ \Omega_M^{\alpha\beta} d_\alpha (\hat{\omega}_{\beta\gamma}) + \hat{\Omega}_M^{\alpha\beta} (\omega_{\beta\gamma}) \hat{d}_\alpha + R^{\alpha\beta\gamma\delta} (\omega_{\alpha\beta}) (\hat{\omega}_{\gamma\delta})$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{closed}} = \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$M = m, \alpha, \hat{\alpha}$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$$

$$+ \left( E_M^{\alpha\beta} \right) \partial Y^M \hat{d}_\alpha + \left( E_M^{\hat{\alpha}\beta} \right) d_\alpha \bar{\partial} Y^M$$

$$+ \left( F^{\alpha\beta} \right) (x, \theta, \hat{\theta}) d_\alpha \hat{d}_\beta$$

$$+ \Omega_M^{\alpha\beta} \partial Y^M (\hat{\omega}_{\alpha\beta}) + \hat{\Omega}_M^{\alpha\beta} (\omega_{\alpha\beta}) \bar{\partial} Y^M$$

$$+ \Omega_M^{\alpha\beta} d_\alpha (\hat{\omega}_{\beta\gamma}) + \Omega_M^{\alpha\beta} (\omega_{\alpha\beta}) \hat{d}_\gamma + R^{\alpha\beta\gamma\delta} (\omega_{\alpha\beta}) (\hat{\omega}_{\gamma\delta})$$

$\omega_x$

Open string

massless

$$V = \lambda^\tau A_\mu(x, \theta)$$

massive

$$V = \lambda^\tau \left( \partial_\theta^\mu A_{\mu\nu}^{(\theta)} + \pi^\mu A_{\mu\nu} + d_\nu A_\mu^\nu + (\omega \gamma_\mu \lambda) A_\mu^\nu + \partial \lambda^\mu \tilde{A}_\mu \right), QV = 0$$

$$Q = \int d\bar{z} \left( \hat{A}^\mu \hat{d}_\mu + (\omega \lambda) A_\mu^\nu \right)$$

$$d_\mu(z) d_\nu(z) \rightarrow \frac{1}{y-z} \pi^\mu \gamma_{\mu\nu}$$

$$\pi^\mu = \partial \theta \gamma^\mu \partial \theta$$

since 2 multiplet

Close d

$$V = \lambda^\tau \hat{\lambda}^\rho A_{\mu\nu}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^\tau \hat{\lambda}^\rho (A_{\mu\nu}^{(\theta)} \times \hat{A}_{\mu\nu}^{(\hat{\theta})})$$

$$= \lambda^\tau \hat{\lambda}^\rho \left( a_m \hat{a}_m(\gamma^\theta)_\nu (\gamma^\theta)_\mu \right)_\rho$$

$$a_m \hat{\lambda}^\nu (\gamma^\theta)_\nu (\gamma^\theta)_\mu (\gamma^\theta)_\rho$$

$$+ \lambda \hat{a}_\mu + \lambda$$



$$V = \lambda \left( \frac{1}{2} A_{\mu\nu}^2 + \dots A_{\mu\nu} + d_Y A_Y + (b_{\mu\nu}) A_{\mu\nu} + \partial \lambda^p A_p \right), QV=0 \rightarrow \text{massless multiplet}$$

Closed

$$V = \lambda^x \hat{\lambda}^p A_{\mu\nu p}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\lambda \gamma^m \lambda = \hat{\lambda} \gamma^m \hat{\lambda} = 0$$

$$\rightarrow \lambda^x \hat{\lambda}^p (A_{\mu\nu}^x \hat{A}_{\mu\nu}^p)$$

$$= \lambda^x \hat{\lambda}^p (a_m \hat{a}_m (\gamma^\theta)_x (\gamma^\theta)_p)$$

$$a_m \hat{\lambda}^x (\gamma^\theta)_x (\gamma^\theta)_p (\gamma^\theta)_p \dots$$

$$= \lambda^x \hat{\lambda}^p \left[ (g_{\mu\nu} + b_{\mu\nu} + \gamma_{\mu\nu} \psi) (\gamma^\mu \theta)_x (\gamma^\nu \hat{\theta})_p + \psi_n^\delta (\gamma^\mu \theta)_x (\gamma^\nu \hat{\theta})_p (\gamma^\delta \hat{\theta})_p + \hat{\psi} + F^{\mu\nu} (\theta^\mu)_x (\hat{\theta}^\nu)_p \right]$$

$\omega_x$

Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

massive

$$V = \lambda^\alpha \left( \partial \theta^\rho A_{\rho\alpha}^{(p)} + \pi^\alpha A_{\alpha m} + d_\gamma A_\alpha^\gamma + (\omega \gamma_\alpha \lambda) A_\alpha^{(m)} + \partial \lambda^\beta \tilde{A}_\beta \right), QV = 0 \rightarrow \text{massive spin } 2 \text{ multiplet}$$

$$Q = \int d\bar{z} \left( \hat{A}^\alpha \hat{d}_\alpha + (\omega \lambda) \hat{A}_\alpha \right)$$

$$d_\alpha^{(p)} d_\beta^{(p)}(z) \rightarrow \frac{1}{z-\bar{z}} \pi^\alpha \gamma_{\alpha\beta}$$

$$\pi^\alpha = \partial \lambda^\alpha + \theta \gamma^\alpha \partial \theta$$

$\hat{K} \theta, (\partial \lambda \partial \theta)$

Close d

$$V = \lambda^\alpha \hat{\lambda}^\beta A_{\alpha\beta}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\lambda \gamma^\alpha \lambda = \hat{\lambda} \gamma^\alpha \hat{\lambda} = 0$$

$$\rightarrow \lambda^\alpha \hat{\lambda}^\beta (A_{\alpha\beta}^{(p)} \times \hat{A}_\beta^{(p)})$$

$$= \lambda^\alpha \hat{\lambda}^\beta \left( a_m \hat{a}_m (\gamma^\alpha \theta)_\gamma (\gamma^\beta \hat{\theta})_\rho + a_m \hat{\chi}^\gamma (\gamma^\alpha \theta)_\gamma (\gamma^\beta \hat{\theta})_\rho (\gamma^\delta \hat{\theta})_\sigma + \dots \right)$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{closed}} = \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{\alpha}$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$$

$$+ \left( E_M^{\alpha} \right) \partial Y^M \hat{d}_\alpha + \left( E_M^{\hat{\alpha}} \right) \partial Y^M \hat{d}_{\hat{\alpha}}$$

$$+ \left( F^{\alpha\beta} \right) (x, \theta, \hat{\theta}) d_\alpha d_\beta$$

$$+ \Omega_M^{\alpha\beta} \partial Y^M (\hat{\omega}_{\alpha\beta}) + \hat{\Omega}_M^{\hat{\alpha}\hat{\beta}} \partial Y^M (\hat{\omega}_{\hat{\alpha}\hat{\beta}})$$

$$+ \Omega^{\alpha\beta} d_\alpha (\hat{\omega}_{\beta\gamma}) + \Omega^{\hat{\alpha}\hat{\beta}} d_{\hat{\alpha}} (\hat{\omega}_{\hat{\beta}\hat{\gamma}}) + R^{\alpha\beta\gamma\delta} (\omega_{\alpha\beta} \omega_{\gamma\delta})$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{closed}} = \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{\alpha}$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^{\hat{\alpha}})$$

$$+ \left( E_M^{\alpha} \right) \partial_x \bar{\partial} Y^M$$

$$+ \left( E_M^{\hat{\alpha}} \right) \partial_x \bar{\partial} Y^M$$

$$+ F^{\alpha\hat{\alpha}}(x, \theta, \hat{\theta})$$

$$+ \Omega_{MN} \partial Y^M \bar{\partial} Y^N$$

$$T_x \equiv \frac{\partial \mathcal{L}}{\partial (\dot{\theta}^\alpha)}$$

$$+ \Omega_{\alpha\hat{\alpha}} \partial_x (\omega_{\alpha\hat{\alpha}}) \bar{\partial} Y^M + \Omega_{\alpha\beta} \partial_x (\omega_{\alpha\beta}) \bar{\partial} Y^M + \Omega_{\hat{\alpha}\hat{\beta}} \partial_x (\omega_{\hat{\alpha}\hat{\beta}}) \bar{\partial} Y^M$$

Close d

$$V = \lambda^x \hat{\lambda}^p A_{x+p}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\rightarrow \lambda^x \hat{\lambda}^p (A(x) \times \hat{A}_p(x))$$

$$= \lambda^x \hat{\lambda}^p (a_m \hat{a}_n (\gamma \theta)_x (\gamma \hat{\theta})_p$$

$$a_m \hat{\lambda}^x (\gamma \theta)_x (\gamma \hat{\theta})_y (\gamma \hat{\theta})_z + \dots) + \lambda \hat{a} + \lambda \hat{\lambda}$$

$$\boxed{\lambda \gamma^m \lambda = \hat{\lambda} \gamma^m \hat{\lambda} = 0}$$

$$\{Q, \hat{Q}\} = 0$$

$$Q^2 = \hat{Q}^2 = 0$$

$$= \lambda^x \hat{\lambda}^p \left( (g_{mn} + b_{mn} + \gamma_n \psi) (\gamma^m \theta)_x (\gamma^p \hat{\theta})_p \right. \\ \left. + \psi_n (\gamma^m \theta)_x (\gamma^p \hat{\theta})_y (\gamma^q \hat{\theta})_p + \hat{\psi} + F^x (\theta^y) (\hat{\theta}^z) \right)$$

Close d

$$V = \lambda^k \hat{\lambda}^p A_{+p}(x, \theta, \hat{\theta})$$

$$QV = \hat{Q}V = 0$$

$$\lambda \gamma^m \lambda = \hat{\lambda} \gamma^m \hat{\lambda} = 0$$

$$\{Q, \hat{Q}\} = 0$$

$$Q^2 = \hat{Q}^2 = 0$$

$$\rightarrow \lambda^k \hat{\lambda}^p (A_{+p}^{(x)} \times \hat{A}_p^{(x)})$$

$$= \lambda^k \hat{\lambda}^p (a_m \hat{a}_n (\gamma^m \theta)_x (\gamma^m \hat{\theta})_p$$

$$a_m \hat{\lambda}^x (\gamma^m \theta)_x (\gamma^m \hat{\theta})_y (\gamma^m \hat{\theta})_z + \dots$$

$$+ \lambda \hat{a} + \lambda \hat{\lambda}$$

$$= \lambda^k \hat{\lambda}^p \left[ (g_{mn} + b_{mn} + \gamma_n \psi) (\gamma^m \theta)_x (\gamma^m \hat{\theta})_p \right.$$

$$\left. + \psi_n^\delta (\gamma^m \theta)_x (\gamma^m \hat{\theta})_y (\gamma^m \hat{\theta})_p + \hat{\psi} + F^{\delta\epsilon} (\theta^\delta)_x (\hat{\theta}^\epsilon)_p \right]$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$S_{\text{cured}} = \int dz d\bar{z} \left( G_{MN}(x, \theta, \hat{\theta}) + B_{MN}(x, \theta, \hat{\theta}) \right) \partial Y^M \bar{\partial} Y^N$$

$$M = m, \alpha, \hat{2}$$

$$Y^M = (x^m, \theta^\alpha, \hat{\theta}^2)$$

$$+ \left( E_M^{\hat{2}} \right) \partial Y^M \hat{d}_2 + \left( E_M^{\hat{1}} \right) d_2 \bar{\partial} Y^M$$

$$+ \left( F^{\hat{2}\hat{2}} \right) (x, \theta, \hat{\theta}) d_2 \hat{d}_2$$

$$+ \hat{\Omega}_M^{ab} \partial Y^M (\hat{\omega}_{ab}) + \hat{\Omega}_M^{ab} (\omega_{ab})$$

$$T_{\hat{2}} \equiv \frac{\partial S}{\partial (\hat{\theta}^2)}$$

$$+ \hat{Q}^{\alpha ab} d_2 (\hat{\omega}_{ab}) + \hat{Q}^{\alpha ab} (\omega_{ab}) \hat{d}_2 + R^{abcd} (\omega_{abcd})$$

$$T_{\mu} \equiv \frac{\partial \mathcal{L}}{\partial (\delta^{\mu})}$$

$$+ \left( \Omega^{abcd} d_2(\omega\gamma_{ab}\lambda) + \Omega_{M}^{ab} \partial Y^M (\omega\gamma_{ab}\lambda) + \Omega_{N}^{ab} (\omega\gamma_{ab}\lambda) \partial Y^N + \Omega^{abcd} (\omega\gamma_{ab}\lambda) \partial_2 (\delta\gamma_{cd}\lambda) \right)$$

$$\int d^2z (A_m \partial X^m - F_{mn} \Psi^m \Psi^n)$$

RNS

$$\int d\tau d\bar{\tau} \left( (g_{mn} + b_{mn} + \gamma_{mn} \Psi) \partial X^m \bar{\partial} X^n + w_m^{ab} \right)$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$





$$M = m, \alpha, \hat{z}$$

$$Y^M = (x^\mu, \theta^a, \hat{\theta}^3)$$

$$T_{-} \equiv \frac{\partial \mathcal{L}}{\partial (\dot{\theta}^a)}$$

$$+ \left( \frac{E_M^{\alpha}}{M} \right) \partial Y^M \hat{d}_\alpha + \left( \frac{E_M^{\alpha}}{M} \right) d_\alpha \bar{\partial} Y^M$$

$$+ \left( \frac{E_M^{\alpha\beta}}{M} \right) (x, \theta, \hat{\theta}) d_\alpha \hat{d}_\beta$$

$$+ \Omega_M^{ab} \partial Y^M (\omega \gamma_{ab} \hat{\lambda}) + \hat{\Omega}_M^{ab} (\omega \gamma_{ab} \hat{\lambda}) \bar{\partial} Y^M$$

$$+ \left( \frac{E_M^{\alpha ab}}{M} \right) d_\alpha (\omega \gamma_{ab} \hat{\lambda}) + \left( \frac{E_M^{\alpha\beta\gamma}}{M} \right) (\omega \gamma_{ab} \hat{\lambda}) \hat{d}_\gamma + R^{abcd} (\omega \gamma_{ab} \hat{\lambda}) (\hat{\omega} \gamma_{cd} \hat{\lambda})$$

$$\alpha' \int d\hat{z}$$

$$+ \alpha' \int d\hat{z} d\hat{z}' \varphi \hat{\theta}$$

$$G_{MN} = E_M^a$$

$$T_{\mu\nu} = \frac{\delta L}{\delta g^{\mu\nu}}$$

$$\begin{aligned} & + \frac{1}{2} \omega_{ab}^{\mu\nu} \partial_\mu \psi^a \partial_\nu \psi^b + \frac{1}{2} \hat{\omega}_{ab}^{\mu\nu} (\omega_{\mu\nu}^{\alpha\beta}) \partial_\alpha \psi^a \partial_\beta \psi^b \\ & + \frac{1}{2} \omega_{ab}^{\mu\nu} \partial_\mu \psi^a \partial_\nu \psi^b + \frac{1}{2} \hat{\omega}_{ab}^{\mu\nu} (\omega_{\mu\nu}^{\alpha\beta}) \partial_\alpha \psi^a \partial_\beta \psi^b \\ & + \alpha' \int d^2\sigma \varphi(\sigma, \bar{\sigma}) \mathcal{R} \end{aligned}$$

$$\int d^2z (A_m \partial X^m + F_{mn} \psi^m \psi^n)$$

RNS

$$\int d\tau d\bar{\tau} (g_{mn} \dot{X}^m \bar{\dot{X}}^n$$

$$+ \omega_m^{ab} \partial X^m \bar{\psi}_a \psi_b + \hat{\omega}_m^{ab} \psi_a \psi_b$$

$$+ \alpha' \int d\tau d\bar{\tau} \varphi \mathcal{R}$$

$$+ R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$T_{\mu\nu} \equiv \frac{\partial \mathcal{L}}{\partial g^{\mu\nu}}$$

$$\begin{aligned} & + \frac{1}{2} \Omega^{ab} \partial_\mu \gamma^M (\omega_{ab})^\mu + \frac{1}{2} \Omega_{ab} \partial_\mu \gamma^M (\omega_{ab})^\mu \\ & + \frac{1}{2} \Omega^{ab} \partial_\mu \gamma^M (\omega_{ab})^\mu + \frac{1}{2} \Omega_{ab} \partial_\mu \gamma^M (\omega_{ab})^\mu + R^{abcd} (\omega_{ab})^\mu (\omega_{cd})^\nu \\ & + \alpha' \int d^2 \tau \varphi(g, \sigma, \bar{\sigma}) \mathcal{R} \end{aligned}$$

$$\int d^2 z (A_m \partial X^m + F_{mn} \psi^m \psi^n)$$

RNS

$$\int d\tau d\bar{\tau} (g_{mn} \dot{X}^m \bar{\dot{X}}^n$$

$$+ \omega_m^{ab} \partial X^m \bar{\psi}_a \bar{\psi}_b + \hat{\omega}_m^{ab} \psi_a \psi_b \bar{\partial} X^m$$

$$+ \alpha' \int d\tau d\bar{\tau} \varphi \mathcal{R} + R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$T_{\mu\nu} \equiv \frac{\partial \mathcal{L}}{\partial (\delta^{\mu\nu})}$$

$$\left( \begin{aligned} & + \hat{\Omega}^{\alpha ab} d_2(\hat{\omega}_{ab}) + \hat{\Omega}^{\alpha 245}(\hat{\omega}_{ab}) d_2 + R^{\alpha bcd}(\hat{\omega}_{ab}) (\hat{\omega}_{cd}) \\ & + \alpha' \int d^2 \tau \varphi(\tau, \sigma, \bar{\sigma}) \mathcal{R} \end{aligned} \right)$$

$$\int d^2 z (A_n \partial X^n + F_{mn} \Psi^m \Psi^n)$$

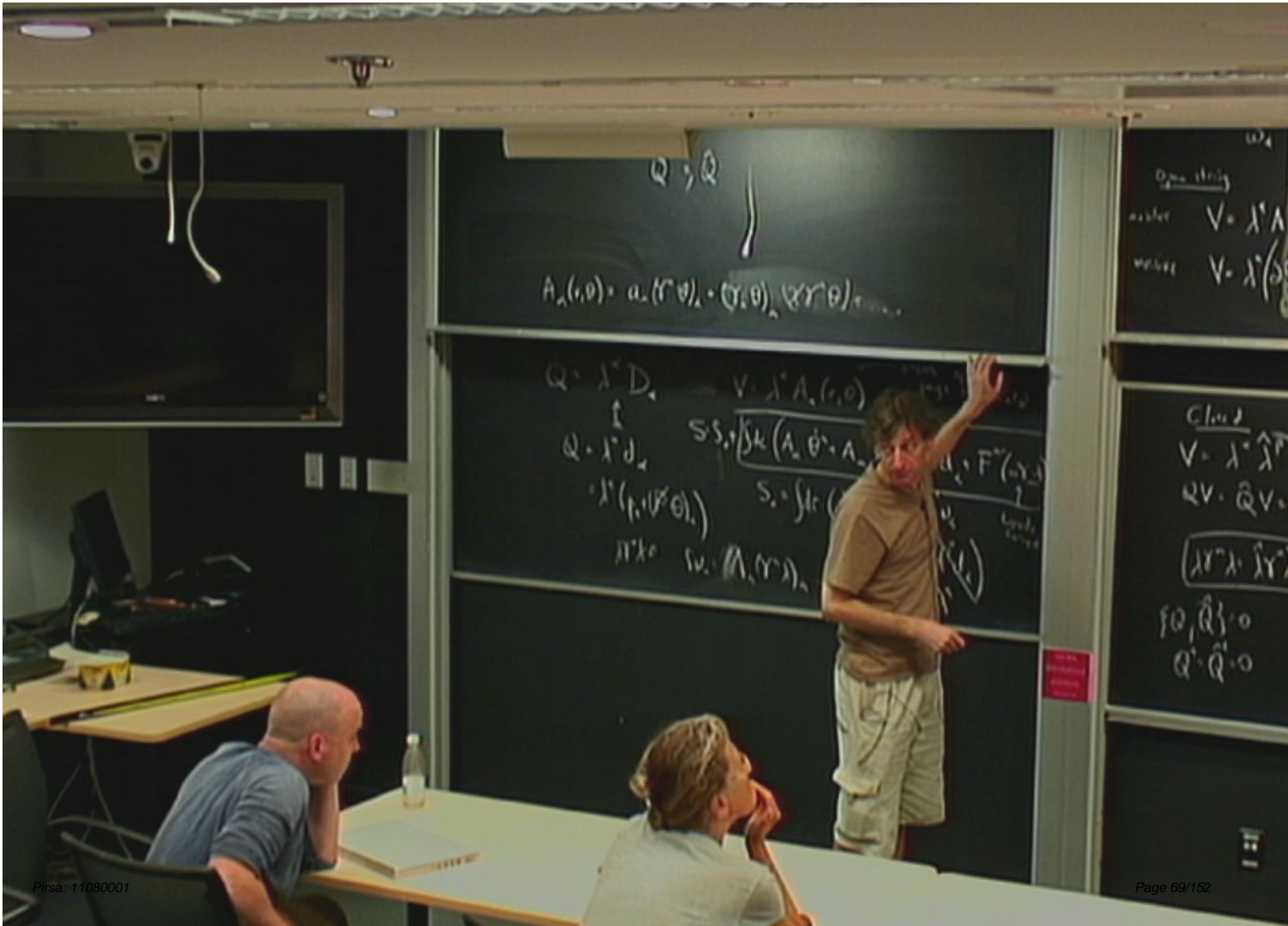
$$\int d\tau d\bar{\tau} ( (g_{mn}, b_{mn}) \partial X^m \bar{\partial} X^n$$

$$+ \omega_n^{ab} \partial X^a \bar{\Psi}_b + \hat{\omega}_n^{ab} \Psi_a \Psi_b \bar{\partial} X^n$$

$$+ \alpha' \int d\tau d\bar{\tau} \varphi \mathcal{R} + R_{abcd} \Psi^a \Psi^b \bar{\Psi}^c \bar{\Psi}^d )$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

RNS



$$Q, \bar{Q}$$

$$A_\mu(r, \theta) = a_\mu(r, \theta) \cdot (r, \theta) \cdot (\gamma, \theta) \dots$$

$$Q = \lambda^2 D_\mu$$

$$V = \lambda^2 A_\mu(r, \theta)$$

$$S = \int d^4x \left( \frac{1}{2} F_{\mu\nu}^2 + \dots \right)$$

$$Q = \lambda^2 D_\mu$$

$$\lambda^2(r, \theta)$$

$$S = \int d^4x \left( \frac{1}{2} F_{\mu\nu}^2 + \dots \right)$$

One string

$$V = \lambda^2 A$$

$$V = \lambda^2 \left( \frac{1}{2} F_{\mu\nu}^2 + \dots \right)$$

Class 2

$$V = \lambda^2 \hat{\lambda}^2$$

$$QV = \bar{Q}V$$

$$\left( \lambda^2 \hat{\lambda}^2 \right)$$

$$\{Q, \bar{Q}\} = 0$$

$$Q = \bar{Q} = 0$$

$$A_\mu(x, \theta) = a_\mu(\gamma^\mu \theta)_\alpha + (\gamma_\mu \theta)_\alpha (\gamma^\mu \theta)^\alpha + \dots$$

$$Q = \int d^4x \mathcal{D}_x$$

$$V = \int d^4x A_\mu(x, \theta)$$

SYM spinors  
gauge super

$$Q = \int d^4x d_x$$

$$= \int d^4x (p_x + (\not{\theta})_x)$$

$$S = S_0 + \int d^4x (A_\mu \dot{\theta}^\mu + A_\mu \dot{x}^\mu + W^2 d_x)$$

$$S_0 = \int dt (\dot{x}^\mu P_\mu + \dot{\theta}^\mu p_\mu + \lambda W_x + \not{P}^2 + \not{P}^\mu \not{P}_\mu)$$

$$\gamma^\mu \gamma^\nu = 0 \quad S \omega_\mu = \cancel{\Lambda_\mu (\gamma^\mu \lambda)_\alpha} \rightarrow (\omega \gamma^\mu \lambda)_\alpha, \omega_\mu \gamma^\mu$$

$$A_\mu(x, \theta) = a_\mu(\gamma^\mu \theta)_\alpha + (\gamma_\mu \theta)_\alpha (\gamma^\mu \theta)^\alpha + \dots$$

$$Q = \int \lambda^\alpha D_\alpha$$

$$\uparrow$$

$$Q = \int \lambda^\alpha d_\alpha$$

$$= \int \lambda^\alpha (p_\alpha + (\not{\partial} \theta)_\alpha)$$

$$\lambda \gamma^\mu \lambda = 0$$

$$V = \int \lambda^\alpha A_\alpha(x, \theta)$$

SYM spinors  
gauge superfield

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_\mu \dot{x}^\mu + W^\alpha d_\alpha + F^{\mu\nu} (\omega \gamma_{\mu\nu} \lambda))$$

$$S_0 = \int dt (\dot{x}^\mu P_\mu + \dot{\theta}^\alpha p_\alpha + \lambda^\alpha \omega_\alpha$$

$$+ \cancel{p^2} + \cancel{(\not{\partial} \lambda)_\alpha})$$

ghost current

$$S \omega_\alpha = \cancel{(\gamma^\mu \lambda)_\alpha} \rightarrow (\omega \gamma^\mu \lambda)_\alpha, \omega_\alpha \lambda^\alpha$$



$$\begin{aligned}
 & \int_{\mathcal{X}} \int_{\mathcal{Y}} \lambda^p A_{\lambda^p}(x, \theta, \hat{\theta}) \rightarrow \int_{\mathcal{X}} \int_{\mathcal{Y}} \lambda^p (A(y) \times \hat{A}_p(x)) \\
 & = \int_{\mathcal{X}} \int_{\mathcal{Y}} \lambda^p (a_m \hat{a}_n (\gamma \theta)_x (\gamma \hat{\theta})_y) \\
 & \quad a_m \hat{\chi}^r (\gamma \theta)_x (\gamma \hat{\theta})_y (\gamma \hat{\theta})_z + \dots \\
 & \quad + \lambda \hat{a} + \lambda \hat{\chi} \\
 & = \int_{\mathcal{X}} \int_{\mathcal{Y}} \lambda^p \left[ (g_{mn} + b_{mn} + \gamma_n \varphi) (\gamma^m \theta)_x (\gamma^m \hat{\theta})_y \right. \\
 & \quad \left. + \psi_n^{\delta} (\gamma^m \theta)_x (\gamma^m \hat{\theta})_y (\gamma^m \hat{\theta})_z + \hat{\psi} + F^{\delta}(\theta^{\dagger}) (\hat{\theta}^{\dagger})_z \right]
 \end{aligned}$$



$$T_{\mu} \equiv \frac{\partial \mathcal{L}}{\partial (\dot{\theta}^{\mu})}$$

$$\left( \int d^4x \left[ \frac{1}{2} \partial_{\mu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\nu} (\omega \gamma_{\nu\mu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\lambda\mu} \lambda) + \frac{1}{2} \partial_{\mu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\nu} (\omega \gamma_{\nu\mu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\lambda\mu} \lambda) \right] + \int d^4x \left[ \frac{1}{2} \partial_{\mu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\nu} (\omega \gamma_{\nu\mu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\lambda\mu} \lambda) \right] + \alpha' \int d^2z \varphi \mathcal{R} \right)$$

$$\int d^2z (A_n \partial X^n + F_{mn} \Psi^m \Psi^n)$$

RNS

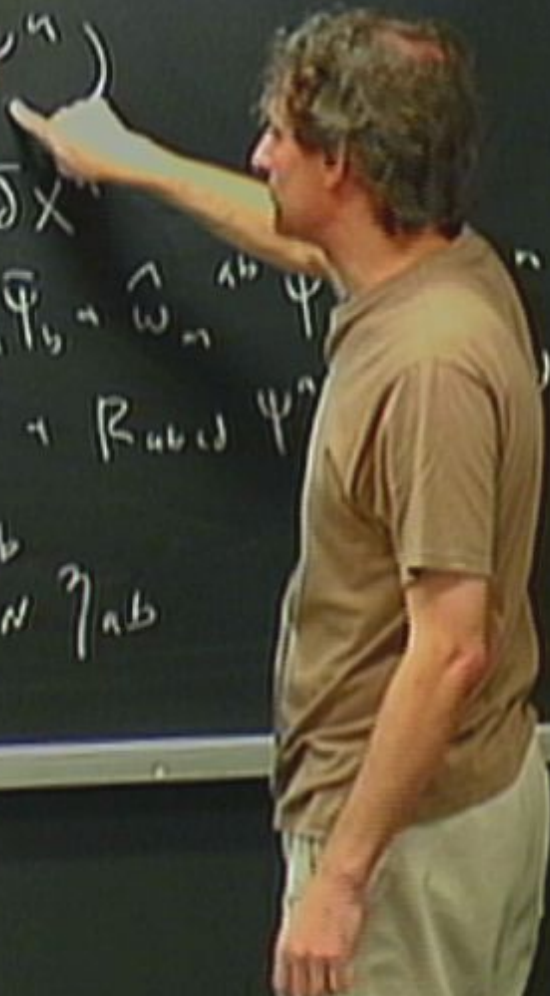
$$\int d^2z d\bar{z} \left( (g_{mn}, b_{mn}) \partial X^m \bar{\partial} X^n \right)$$

$$+ \omega_m^{ab} \partial X^m \hat{\Psi}_a \hat{\Psi}_b + \hat{\omega}_m^{ab} \bar{\partial} X^m \hat{\Psi}_a \hat{\Psi}_b$$

$$+ \alpha' \int d^2z d\bar{z} \varphi \mathcal{R}$$

$$+ R_{abcd} \Psi^a \Psi^b \Psi^c \Psi^d$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$



$$T_{\mu\nu} \equiv \frac{\partial \mathcal{L}}{\partial g^{\mu\nu}}$$

$$\left( \int d^4x \left( \frac{1}{2} \partial_\mu \chi^a \partial^\mu \chi^a + \frac{1}{2} \partial_\mu \psi^m \partial^\mu \psi^m + \frac{1}{2} \partial_\mu \lambda^i \partial^\mu \lambda^i \right) + \int d^4x \left( \frac{1}{2} \partial_\mu \chi^a \partial^\mu \chi^a + \frac{1}{2} \partial_\mu \psi^m \partial^\mu \psi^m + \frac{1}{2} \partial_\mu \lambda^i \partial^\mu \lambda^i \right) + \int d^4x \left( \frac{1}{2} \partial_\mu \chi^a \partial^\mu \chi^a + \frac{1}{2} \partial_\mu \psi^m \partial^\mu \psi^m + \frac{1}{2} \partial_\mu \lambda^i \partial^\mu \lambda^i \right) \right)$$

RNS

$$\int dz (A_m \partial X^m + F_{mn} \psi^m \psi^n) \quad N^m = \psi^m \bar{\psi}^m$$

$$\int dz d\bar{z} \left( (g_{mn}, b_{mn}) \partial X^m \bar{\partial} X^n + \omega_m^{ab} \partial X^m \bar{\psi}_a \bar{\psi}_b + \hat{\omega}_m^{ab} \psi_a \psi_b \bar{\partial} X^m + R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d \right)$$

$$N^m N^n \rightarrow \frac{\delta^m_n}{(z_1 - z_2)^2}$$

$$N_1 + N_2 \quad \begin{matrix} h_1 = +4 \\ h_2 = -3 \end{matrix}$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$T_{\mu} \equiv \frac{\partial \mathcal{L}}{\partial (\delta^{\mu})}$$

$$\left( \int d^4x \left[ \frac{1}{2} \partial_{\mu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\nu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) \right] + \int d^4x \left[ \frac{1}{2} \partial_{\mu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\nu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) \right] + \int d^4x \left[ \frac{1}{2} \partial_{\mu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\nu} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) + \frac{1}{2} \partial_{\lambda} (\omega \gamma_{\mu\nu} \lambda) \right] \right)$$

$$\mathcal{L} = (A_m \partial X^m + F_{mn} \psi^m \psi^n)$$

$$N^m = \psi^m \psi^m$$

$$N^m N^m \rightarrow \frac{1}{(2\pi)^2}$$

$$N_1 \rightarrow N_2$$

$$\left( \begin{array}{c} k_0 = 4 \\ l_1 = 3 \end{array} \right)$$

RNS

$$\left( (g_{mn}, b_{mn}) \partial X^m \bar{\partial} X^n \right)$$

$$+ \omega_m^{ab} \partial X^m \bar{\psi}_a \bar{\psi}_b + \hat{\omega}_m^{ab} \psi_a \psi_b \bar{\partial} X^m$$

$$\left( \varphi R + R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d \right)$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$T_{\mu\nu} \equiv \frac{\partial \mathcal{L}}{\partial g^{\mu\nu}}$$

$$\left( \frac{1}{2} \epsilon^{abcd} d_\mu (\omega \gamma_{ab}) + \frac{1}{2} \epsilon^{abcd} (\omega \gamma_{ab}) \hat{d}_\mu + R^{abcd} (\omega \gamma_{ab}) (\hat{\delta} \gamma_{cd}) \right) + \alpha' \int d^2 \tau \varphi(G, \theta, \bar{\theta}) \mathcal{R}$$

$$\int dz (A_m \partial X^m + F_{mn} \psi^m \psi^n)$$

$$N^m = \psi \bar{\psi}$$

$$N^m N^n \rightarrow \frac{\delta}{(2\pi)^2}$$

$$N_1 \rightarrow N_2$$

$$\boxed{\begin{matrix} k_0 = 4 \\ l_{1,2} = 3 \end{matrix}}$$

$$\int dz d\bar{z} (g_{mn} \partial X^m \bar{\partial} X^n)$$

$$+ \omega_m{}^{ab} \partial X^m \hat{\psi}_a \bar{\psi}_b + \hat{\omega}_m{}^{ab} \psi_a \psi_b \bar{\partial} X^m$$

$$+ \alpha' \int dz d\bar{z} \varphi \mathcal{R} + R_{abcd} \psi^a \psi^b \bar{\psi}^c \bar{\psi}^d$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$\partial(\theta) \quad | \quad + \int d_2(\omega_{\mu\nu}) + \int d_2(\omega_{\mu\nu}) + R(\omega_{\mu\nu})(\delta\delta_{\mu\nu})$$

$$+ \alpha' \int d^2z \varphi(x, \theta, \bar{\theta}) \mathcal{R}$$

$$\int d^2z (A_m \partial X^m + F_{mn} \Psi^m \Psi^n) \quad N^{\alpha\beta} = \Psi^\alpha \Psi^\beta$$

$$N^{\alpha\beta} N^{\gamma\delta} \rightarrow \frac{\delta^2}{(\gamma+\delta)^2}$$

RNS

$$\int d^2z d\tau d\bar{\tau} (g_{mn} \dot{X}^m \dot{X}^n + \omega_m^{ab} \partial X^m \hat{\Psi}_a \hat{\Psi}_b + \hat{\omega}_m^{ab} \Psi_a \Psi_b \bar{\partial} X^m)$$

$$N_1 = N_2$$

$k_0 = 4$
$k_1 = -5$

(w.r.t)

$$+ \alpha' \int d^2z d\tau d\bar{\tau} \varphi \mathcal{R} + R_{abcd} \Psi^a \Psi^b \bar{\Psi}^c \bar{\Psi}^d$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$Y^M = (x^m, \theta^+, \theta^-)$$

$$T_{-} \equiv \frac{\partial \mathcal{L}}{\partial(\dot{\theta}^+)}$$

$$\begin{aligned} & + \hat{\Omega}^{ab} d_2(\omega \gamma_{ab} \lambda) + \hat{\Omega}_m^{ab} (\omega \gamma_{ab} \lambda) \bar{\partial} Y^m \\ & + \hat{\Omega}^{ab} d_2(\omega \gamma_{ab} \lambda) + \hat{\Omega}^{ab} (\omega \gamma_{ab} \lambda) \hat{d}_2 + R^{abcd} (\omega \gamma_{ab} \lambda) (\hat{\delta} \gamma_{cd} \lambda) \\ & + \alpha' \int d^2 z \varphi(g, \theta, \bar{\theta}) \mathcal{R} \end{aligned}$$

$$\int d^2 z (A_m \partial X^m + F_{mn} \Psi^m \Psi^n) \quad N^{\alpha\beta} = \Psi^\alpha \bar{\Psi}^\beta$$

RNS

$$\int d^2 z d\bar{z} (g_{mn}, b_{mn}) \partial X^m \bar{\partial} X^n$$

$$+ \omega_m^{ab} \partial X^m \bar{\Psi}_a \bar{\Psi}_b$$

(wY)

$$+ \alpha' \int d^2 z d\bar{z} \varphi \mathcal{R}$$

$$N^{\alpha\beta} N^{\gamma\delta} \rightarrow \frac{\delta^{\alpha\gamma} \delta^{\beta\delta}}{(y_1 + 1)^2}$$

$$N_1 + N_2$$

$$\begin{array}{|c|} \hline k_0 = +4 \\ \hline l_1 = -5 \\ \hline \end{array}$$

$$\Psi_c \bar{\partial} X^c + \Psi^c \bar{\Psi}_c \bar{\Psi}^d$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$Y^M = (x^m, \theta^a, \bar{\theta}^{\dot{a}})$$

$$T_{\mu\nu} \equiv \frac{\partial \mathcal{L}}{\partial (\dot{\theta}^\mu)}$$

$$+ \Phi^{ab} d_2(\omega_{ab}) + \Omega^{ab} \partial Y^M (\omega_{ab}) + \hat{\Omega}_m^{ab} (\omega_{ab}) \bar{\partial} Y^M + R^{abcd} (\omega_{ab}) (\delta \gamma_{cd}) + \alpha' \int d^2z \varphi(g, \theta, \bar{\theta}) \mathcal{R}$$

$$\int dz (A_m \partial X^m + F_{mn} \Psi^m \Psi^n)$$

$$N^m = \Psi \bar{\Psi}$$

RNS

$$\int dz d\bar{z} (g_{mn} b_{mn}) \partial X^m \bar{\partial} X^n$$

$$\frac{\partial}{\partial (y \cdot t)^2}$$

$k_0 = +4$
$k_1 = -3$

(wry)

$$g_{mn} b_{mn} \partial X^m \bar{\partial} X^n + \alpha' \int dz d\bar{z} \varphi \mathcal{R}$$

$$G_{MN} = E_M^a E_N^b \eta_{ab}$$

$$A_\mu(x, \theta) = a_m(t, \theta)_\mu + (A_n \theta)_\mu(x, \theta) + \dots$$

$$\lambda^\mu D_\mu$$

$$V = \lambda^\mu A_\mu(x, \theta)$$

SYM spin-1 gauge superfield

$$S = S_0 + \int d^4x \left( A_\mu \dot{\theta}^\mu + A_m \dot{x}^m + W^\mu d_\mu + F^{mn}(\omega \gamma_{mn}) \right)$$

$$S_0 = \int dt \left( \dot{x}^m P_m + \dot{\theta}^\mu p_\mu + \lambda W_\mu \right)$$

local current

$$= \lambda^\mu (p_\mu + (\cancel{V} \theta)_\mu)$$

$\lambda \gamma^m \lambda = 0$

$$\delta W_\mu = \left( \Lambda_n (\gamma^m \lambda)_\alpha \rightarrow (\omega \gamma^m \lambda)_\alpha, \omega_\mu \lambda^\mu \right)$$



$$A_\mu(x, \theta) = a_m(t, \theta)_\mu + (v_n \theta)_\mu + (x_0, \theta)_\mu + \dots$$

$$Q = \lambda^\mu D_\mu$$

$$V = \lambda^\mu A_\mu(x, \theta)$$

SYM spinors  
gauge superfield

$$Q = \lambda^\mu d_\mu$$

$$= \lambda^\mu (p_\mu + (i \not{\partial} \theta)_\mu)$$

$\lambda \gamma^\mu \lambda = 0$

$$S = S_0 + \int d^4x (A_\mu \dot{\theta}^\mu + A_m \dot{x}^m + W^{\mu\nu} d_\nu + F^{\mu\nu} (\omega \gamma_{\mu\nu} \lambda))$$

$$S_0 = \int dt (\dot{x}^\mu p_\mu + \dot{\theta}^\mu p_\mu + \lambda^\mu \omega_\mu$$

$$+ \not{p}^2 + \cancel{(\not{\partial} \theta)_\mu \lambda^\mu})$$

Gravitational current

$$\delta \omega_\mu = \cancel{\Lambda_\mu (\gamma^\mu \lambda)}_\alpha \rightarrow (\omega \gamma^{\mu\nu} \lambda), \omega_\mu \lambda^\mu$$

$$Y^M = (x^m, \theta, \bar{\theta})$$

$$T_{\mu} \equiv \frac{\partial \mathcal{L}}{\partial (\dot{\theta}^{\mu})}$$

$$\int d^2x d^2\theta \left( \frac{1}{2} \Phi^{ab} d_a(\omega_{\mu\nu}) + \frac{1}{2} \hat{\Phi}^{ab}(\omega_{\mu\nu}) \hat{d}_a + R^{abcd}(\omega_{\mu\nu})(\hat{\delta}\gamma_{\nu\lambda}) \right) + \alpha' \int d^2\theta \varphi(x, \theta, \bar{\theta}) \mathcal{Q}$$

$$\int d^2z (A_{\mu\nu} \dot{Y}^{\mu} \dot{Y}^{\nu} + F_{mn} \Psi^m \Psi^n)$$

$$N^{\mu\nu} = \Psi^{\mu} \bar{\Psi}^{\nu}$$

$$N^{\mu\nu} N^{\rho\sigma} \rightarrow \frac{\delta^{\mu\rho} \delta^{\nu\sigma}}{(2+1)^2}$$

$$N_1 + N_2 \quad \left( \begin{array}{c} k_1 + 4 \\ h_1 - 5 \end{array} \right)$$

$$\int d^2x d^2\bar{x} \left( \frac{1}{2} \partial X^{\mu} \bar{\partial} X^{\nu} + \frac{1}{2} \partial X^{\mu} \hat{\Psi}_a \bar{\Psi}_b + \hat{\omega}_{\mu\nu} \Psi_a \Psi_b \bar{\partial} X^{\nu} + R_{abcd} \Psi^a \Psi^b \bar{\Psi}^c \bar{\Psi}^d \right)$$

$$E_N^a E_N^b \eta_{ab}$$



$$Y^{\mu} = (x^{\mu}, \theta, \bar{\theta})$$

$$p_{\mu} \equiv \frac{\partial \mathcal{L}}{\partial \dot{Y}^{\mu}}$$

$$\begin{aligned} & + \int d^2z \left( \frac{1}{2} \eta_{ab} \dot{X}^{\mu} \dot{X}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\psi}^{\mu} \dot{\psi}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\bar{\psi}}^{\mu} \dot{\bar{\psi}}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} \right) \\ & + \int d^2z \left( \frac{1}{2} \eta_{ab} \dot{X}^{\mu} \dot{X}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\psi}^{\mu} \dot{\psi}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\bar{\psi}}^{\mu} \dot{\bar{\psi}}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} \right) \\ & + \int d^2z \left( \frac{1}{2} \eta_{ab} \dot{X}^{\mu} \dot{X}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\psi}^{\mu} \dot{\psi}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\bar{\psi}}^{\mu} \dot{\bar{\psi}}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} \right) \end{aligned}$$

$$\int d^2z (A_{\mu} \partial X^{\mu} + F_{mn} \Psi^m \Psi^n)$$

$$N^{\mu\nu} = \Psi^{\mu} \bar{\Psi}^{\nu}$$

$$N^{\mu\nu} N^{\rho\sigma} \rightarrow \frac{\delta^{\mu\rho} \delta^{\nu\sigma}}{(2+1)^2}$$

PNS

$$\int d^2z \left( (g_{mn} + b_{mn}) \dot{X}^m \dot{X}^n \right)$$

$$N_1 + N_2$$

$$\begin{matrix} k_1 = 4 \\ k_2 = 5 \end{matrix}$$

$$+ \omega_{mn} \dot{X}^m \dot{\psi}^n \bar{\psi}^{\mu} + \hat{\omega}_{mn} \dot{\psi}^m \dot{\psi}^n \bar{\psi}^{\mu}$$

(10.2)

$$\int d^2z \left( \frac{1}{2} \eta_{ab} \dot{X}^{\mu} \dot{X}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\psi}^{\mu} \dot{\psi}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} + \frac{1}{2} \eta_{ab} \dot{\bar{\psi}}^{\mu} \dot{\bar{\psi}}^{\nu} \gamma_{\mu\nu}^{\alpha\beta} \right)$$

$$G_{\mu\nu} = E_{\mu}^a E_{\nu}^b \eta_{ab}$$

$$\int dt \left( P(\dot{x}^m - \gamma^m \dot{\theta}) + e P^* P_2 \right)$$

$m = 0, \dots, 10$   
 $k = 1, \dots, 32$

$$\int dt \left( P_m \dot{x}^m - \gamma_n \dot{\theta}^n \right) + e P^m P_m$$

$$m = 0, \dots, 10$$

$$n = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_n \dot{\theta}^n + \omega_n \dot{\chi}^n \right)$$

$$\begin{Bmatrix} D_{\chi^m} \\ D_{\theta^n} \end{Bmatrix} = Y^m P_m$$

$$Q = \chi^m D_m$$

$$\chi^m \dot{\chi}^m =$$

$$\int dt \left( P_m \dot{x}^m - \theta \gamma_n \dot{\theta} \right) + e P^m P_m$$

$$m = 0, \dots, 10$$

$$k = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_k \dot{\theta}^k + \omega_k J^k \right)$$

$$\{ D_{\gamma} D_{\beta} \} = \gamma^{\alpha} P_{\alpha}$$

$$Q = J^k D_k$$

$$0 = R^{\mu\nu} R_{\mu\nu} = 0$$

$$\int dt \left( P_m \dot{x}^m - \dot{\theta}^k \gamma_{kl} \dot{\theta}^l + e P^m P_m \right)$$

$$m = 0, \dots, 10$$

$$k = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_k \dot{\theta}^k + \omega_k \dot{\theta}^k \right)$$

$$\begin{cases} D_k D_l \\ \gamma_{kl} D_l \end{cases} = Y^m P_m$$

$$Q = \lambda^k D_k$$

$$\lambda^m \dot{\theta}^m = 0$$

V<sub>2</sub>

$$Q = \int dx \, D_x$$

$$Q = \int dx \, d_x$$

$$= \int dx \, (p_x + (\not{D} \theta)_x)$$

$$\not{D} \theta = 0$$

$$V = \int dx \, A_x(x, \theta)$$

SYM spinor gauge superfield

$$S = S_0 + \int dx \, (A_x \dot{\theta}^x + A_m \dot{x}^m + W^a d_x + F^{mn} (\gamma_{mn})_x)$$

$$S_0 = \int dt \, (\dot{x}^m p_m + \dot{\theta}^x p_x + \lambda \omega_x$$

$$+ \cancel{p^2} + \cancel{(\not{D} \theta)_x})$$

Gravitational current

$$\delta \omega_x = \Lambda_m (\gamma^m \lambda)_x \rightarrow (\omega \gamma^m \lambda)_x, \omega_x \lambda^x$$



$$\int dt \left( P_m \dot{x}^m - \dot{\theta} \gamma_n \dot{\theta} \right) + e P^m P_m$$

$$m = 0, \dots, 10$$

$$k = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_k \dot{\theta}^k + \omega_k \dot{\theta}^k \right)$$

$$\left\{ \begin{array}{l} D_k D_k \\ \gamma_k D_k \end{array} \right\} = \gamma_k P_k$$

$$Q = \lambda^k D_k$$

$$\lambda^m \dot{\theta}^m = 0$$

$$\int dt \left( P_m \dot{x}^m - \dot{\theta} \gamma_n \dot{\theta} \right) + e P^1 P_2$$

$$m = 0, \dots, 10$$

$$k = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_k \dot{\theta}^k + \omega_k \dot{\chi}^k \right)$$

$$\{D_{\mu}, D_{\nu}\} = \gamma_{\mu\nu}^{\lambda} P_{\lambda}$$

$$Q = \lambda^k D_k$$

$$\lambda^m \lambda_k = 0$$

$$V = \lambda^k \lambda_k$$

spin 2 multiplet

$$\int dt \left( P_m \dot{x}^m - \dot{\theta} \gamma_n \dot{\theta} \right) + e P^1 P_2$$

$$m = 0, \dots, 10$$

$$k = 1, \dots, 32$$

$$\{D_{\mu}, D_{\nu}\} = \gamma_{\mu\nu}^{\alpha} P_{\alpha}$$

$$\int dt \left( P_m \dot{x}^m + P_k \dot{\theta}^k + \omega_k \dot{\chi}^k \right)$$

$$Q = \lambda^{\alpha} D_{\alpha}$$

$$\lambda^{\alpha} \gamma_{\alpha} = 0$$

$$V = \lambda^{\alpha} \lambda^{\beta} \lambda^{\gamma} A_{\alpha\beta\gamma}(x, \theta)$$

$$QV = 0$$

$$\Rightarrow A_{\alpha\beta\gamma}(\dot{\theta}^{\alpha}, \dot{\theta}^{\beta}, \dot{\theta}^{\gamma})$$

$b_{map}$

+ ...

$$Q = \lambda^\alpha D_\alpha$$

$$\uparrow$$

$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{D}\theta)_\alpha)$$

$$\lambda \gamma^\mu \lambda = 0$$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spinor gauge superfield

$$S = S_0 + \int d^4x (A_\alpha \dot{\theta}^\alpha + A_m \dot{x}^m + W^2 d_\alpha + F^{\alpha\beta} (\omega \gamma_{\alpha\beta}))$$

$$S_0 = \int dt (\dot{x}^\mu P_\mu + \dot{\theta}^\alpha p_\alpha + \lambda^\alpha \omega_\alpha$$

$$+ \not{D}^2 + (\not{D}\theta)_\alpha \lambda^\alpha)$$

logarithmic current

$$S_{\omega_2} = \int d^4x (\gamma^\mu \lambda)_\alpha \rightarrow (\omega \gamma^\mu \lambda)_\alpha, \omega_\alpha \lambda^\alpha$$

$$\int dt \left( P_m \dot{x}^m - \gamma_n \dot{\theta}^n + e P^* P_m \right)$$

$$m = 0, \dots, 10$$

$$n = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_n \dot{\theta}^n + \omega_\alpha \lambda^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = Y^* P_m$$

$$Q = \lambda^\alpha D_\alpha$$

$$\lambda^\alpha \lambda^\beta = 0$$

$$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x, \theta)$$

$QV = 0$   
 $\Rightarrow A_{\alpha\beta\gamma} = (\delta^\alpha_\beta)(\delta^\beta_\gamma)(\delta^\gamma_\alpha)$   
 $b_{\alpha\beta\gamma}$   
 $+ \dots$

$$\int dt \left( P_m \dot{x}^m - \gamma_n \dot{\theta}^n + e P^* P_m \right)$$

$$m = 0, \dots, 10$$

$$n = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_n \dot{\theta}^n + \omega_\alpha \dot{\chi}^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = Y^* P_m$$

$$Q = \lambda^\alpha D_\alpha$$

$$\lambda^\alpha \lambda^\beta = 0$$

$$V = \lambda^\alpha \lambda^\beta \lambda^\gamma A_{\alpha\beta\gamma}(x, \theta)$$

$$QV = 0$$

$$\rightarrow A_{\alpha\beta\gamma} = (\delta^\alpha_1)(\delta^\beta_2)(\delta^\gamma_3) + \dots$$

$$b_{\alpha\beta\gamma}$$

$$\int dt \left( P_m \dot{x}^m - i \Theta \gamma_m \dot{\Theta} \right) + e P$$

$$m = 0, \dots, 10$$

$$\alpha = 1, \dots, 32$$

$$\int dt \left( P_m \dot{x}^m + P_\alpha \dot{\Theta}^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = \gamma_{\alpha\beta}^m P_m$$

$$Q = \int dt$$

$$V = \lambda^{\alpha\beta\gamma} A_{\alpha\beta\gamma}(x, \Theta)$$

$$QV = 0$$

$$\Rightarrow A_{\alpha\beta\gamma} = (\delta^\alpha_\beta)(\delta^\beta_\gamma)(\delta^\gamma_\alpha)$$

$$b_{\alpha\beta\gamma}$$

$$+ \dots$$

$$\int dt \left( P_m \dot{x}^m - i \Theta \gamma_m \dot{\Theta} \right) + e P^{\mu} P_{\mu} \quad / \quad V = \lambda^{\mu} \lambda^{\nu} A_{\mu\nu}(x, \theta)$$

$$m = 0, \dots, 10$$

$$\alpha = 1, \dots, 32$$

$$\int ds \left( P_m \dot{x}^m + p_{\alpha} \dot{\theta}^{\alpha} + \omega_{\alpha} \dot{\psi}^{\alpha} \right)$$

$$(i\sigma_2) (i\sigma_0) (i\sigma_3)$$

$$b_{\mu\nu\rho}$$

$$\{D_{\alpha}, D_{\beta}\} = \gamma_{\alpha\beta}^{\mu} P_{\mu}$$

$$Q = \int ds_1 ds_2 \lambda d$$



$$\int dt \left( P_m \dot{x}^m - \gamma_n \dot{\theta}^n \right) + e P^* P_m$$

$$m = 0, \dots, 10$$

$$n = 1, \dots, 32$$

$$\int ds \left( P_m \dot{x}^m + P_n \dot{\theta}^n + \omega_n \lambda^n \right)$$

$$\left\{ \begin{matrix} D_x \\ D_p \end{matrix} \right\} = Y^* P$$

$$Q = \int ds ds_2 \lambda d$$

$$\lambda \gamma^m \lambda = 0$$

$$V = \lambda^* \lambda^* \lambda^* A$$

$$QV = 0$$

$$\rightarrow A_{\mu p i} (\delta \theta)_2 (\delta \theta)_1$$

$$+ \dots$$

$$\int dt \left( P_m \dot{x}^m - \gamma_n \dot{\theta}^n \right) + e P^{\mu} P_{\mu}$$

$$m = 0, \dots, 10$$

$$n = 1, \dots, 32$$

$$\int ds \left( P_m \dot{x}^m + P_{\alpha} \dot{\theta}^{\alpha} + \omega_{\alpha} \dot{\lambda}^{\alpha} \right)$$

$$\{D_{\alpha} D_{\beta}\} = \gamma_{\alpha\beta} P_m$$

$$Q = \int ds ds_{\alpha} \dot{\lambda}^{\alpha}$$

$$\dot{\lambda}^{\alpha} \dot{\lambda}_{\alpha} = 0$$

$$V = \lambda^{\alpha} \lambda^{\beta} \lambda^{\gamma} A_{\alpha\beta\gamma}(x, \theta)$$

$$QV = 0$$

$$\rightarrow A_{\alpha\beta\gamma} = (\dot{\theta}^{\alpha})_2 (\dot{\theta}^{\beta})_1 (\dot{\theta}^{\gamma})_3$$

$$b_{\alpha\beta\gamma}$$

$$+ \dots$$

Martin Cederwall

$$Q = \lambda^\alpha D_\alpha$$



$$Q = \lambda^\alpha d_\alpha$$

$$= \lambda^\alpha (p_\alpha + (\not{D}\Theta)_\alpha)$$

$\lambda^\alpha \lambda_\alpha = 0$   $\not{D}\omega_\alpha$

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

SYM spinor gauge superfield

$$S = \int d^4x \left( \dot{\theta}^\alpha + A_\alpha \dot{x}^\alpha + W^\alpha d_\alpha + F^{mn}(\omega \gamma_{mn}) \right)$$

ghost current

$$\rightarrow (\omega \gamma^{mn} \lambda), \omega \gamma_\alpha \lambda$$

$\langle \varphi Q \varphi \rangle$

$$\int d\tau \left( P_m \dot{x}^m - i \dot{\theta} \gamma_n \dot{\theta} \right) + e P^+ P^-$$

$m = 0, \dots, 10$   
 $\alpha = 1, \dots, 32$

$$\int d\tau \left( P_m \dot{x}^m + P_\alpha \dot{\theta}^\alpha + \omega_\alpha \lambda^\alpha \right)$$

$$\{D_\alpha, D_\beta\} = \gamma_{\alpha\beta}^m P_m$$

$$Q = \int ds_1 ds_2 \lambda^\alpha ds_\alpha$$

$$\lambda^\alpha \lambda^\alpha = 0$$

$V = \lambda^\alpha \lambda^\beta A_{\alpha\beta}(x, \theta)$   
 $QV = 0$   
 $\Rightarrow A_{\alpha\beta} = (\delta^\alpha_\beta) (\dot{\theta}^\alpha) (\dot{\theta}^\beta)$   
 $k_{map}$   
+ ...

$$\langle \varphi Q \varphi^\dagger \varphi \rangle \int d\tau \left( P_m \dot{x}^m - i \Theta \gamma_n \dot{\Theta} \right) + e P^\mu P_\mu$$

$$m = 0, \dots, 10$$

$$n = 1, \dots, 32$$

$$\int d\tau \left( P_m \dot{x}^m + P_\alpha \dot{\Theta}^\alpha + \omega_\alpha \dot{\lambda}^\alpha \right)$$

$$\{ D_\mu, D_\nu \} = \gamma_{\mu\nu} P_m$$

$$Q = \int ds ds_2 \lambda^\alpha ds_1$$

$$\lambda \gamma^\mu \lambda = 0$$

$$V = \lambda^\mu \lambda^\nu A_{\mu\nu}(x, \theta)$$

$$QV = 0$$

$$\Rightarrow A_{\mu\nu} = (\delta\theta)_\mu (\delta\theta)_\nu (\delta\theta)_\rho$$

$$b_{\mu\nu\rho}$$

$$+ \dots$$

$$\langle \varphi | Q | \varphi \rangle = \int d\tau \left( P_m \dot{x}^m - i \dot{\theta} \gamma_m \dot{\theta} \right) + e P^+ P^-$$

$$m = 0, \dots, 10$$

$$k = 1, \dots, 32$$

$$\int d\tau \left( P_m \dot{x}^m + P_{\alpha} \dot{\theta}^{\alpha} + \omega_{\alpha} j^{\alpha} \right)$$

$$\{ D_{\alpha}^{\dagger}, D_{\beta} \} = \gamma_{\alpha\beta} P_m$$

$$Q = \int d\sigma_1 d\sigma_2 \lambda^{\alpha} d_{\alpha}$$

$$\lambda \gamma^m \lambda = 0$$

$$V = \lambda^{\alpha} \lambda^{\beta} \lambda^{\gamma} A_{\alpha\beta\gamma}$$

$$QV = 0$$

$$\Rightarrow A_{\alpha\beta\gamma} = (\delta^{\alpha}_1 \delta^{\beta}_2 \delta^{\gamma}_3) + \dots$$

$$b_{m,p}$$

$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\psi}_{\dot{\alpha}}$$

$$\omega_\alpha$$

Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

massive

$$V = \lambda^\alpha \left( \partial \theta^{\dot{\alpha}} A_{\dot{\alpha}}^{(20)} + \pi^m A_{\dot{\alpha} m} + d_Y A_Y + (\omega) \chi \right)$$

$$S = \int dz \left( \partial X^\alpha \bar{\partial} X_\alpha + \omega_\alpha \bar{\partial} \theta^\alpha + \omega_{\dot{\alpha}} \bar{\partial} \lambda^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \bar{\partial} \hat{\lambda}^{\dot{\alpha}} \right)$$

$$Q = \int dz$$

$$\hat{Q} = \int dz$$

$$+ (\omega)$$

$$d_\alpha = p_\alpha + \theta^\beta \theta_\beta, (\theta^\alpha \partial_\alpha) \chi_\alpha$$

$$d_\alpha^{\dot{\beta}} d_{\dot{\beta}}^\alpha \rightarrow \frac{1}{y-2} \pi^m \chi_{m-\alpha}$$

$$\pi^m = \partial X^m + \theta^\alpha \gamma^m \partial \theta$$

$\rightarrow$  massive spin 2 multiplet

$$x^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$\omega_\alpha$$

Open string

massless  $V = \lambda^\alpha A_\alpha(x, \theta)$

massive  $V = \lambda^\alpha \left( \partial \theta^{\dot{\alpha}} A_{\dot{\alpha}}^{(0)} + \pi^m A_{\dot{\alpha} m} + d_\gamma A_{\dot{\alpha} \gamma} + \dots \right)$

$$S = \int dz \left( \dot{x}^\mu \bar{p}_\mu + p_\alpha \dot{\theta}^\alpha + \omega_\alpha \dot{\lambda}^\alpha + \hat{p}_{\dot{\alpha}} \dot{\hat{\theta}}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \dot{\hat{\lambda}}^{\dot{\alpha}} \right)$$

$$Q = \int dz \left( p_\alpha + \theta^\alpha \theta_\alpha \right), \quad \hat{Q} = \int dz \left( \hat{p}_{\dot{\alpha}} + \hat{\theta}^{\dot{\alpha}} \hat{\theta}_{\dot{\alpha}} \right)$$

$$d_p(z) = \frac{1}{y-z} \pi^\alpha \gamma_{\alpha\beta} \dots$$

$$\pi^\alpha = \partial x^\alpha + \theta^\alpha \partial \theta$$

$$QV = 0 \rightarrow \text{massive spin } \frac{1}{2} \text{ multiplet}$$



$$X^m, \theta^\alpha, \hat{\theta}^{\dot{\alpha}}, \lambda^\alpha, \hat{\lambda}^{\dot{\alpha}}$$

$$p_\alpha, \hat{p}_{\dot{\alpha}}, \psi_\alpha, \hat{\omega}_{\dot{\alpha}}$$

$$S = \int dz \left( \partial X^m \bar{\partial} X_m + p_\alpha \bar{\partial} \theta^\alpha + \omega_\alpha \bar{\partial} \lambda^\alpha + \hat{p}_{\dot{\alpha}} \partial \hat{\theta}^{\dot{\alpha}} + \hat{\omega}_{\dot{\alpha}} \partial \hat{\lambda}^{\dot{\alpha}} \right)$$

$\omega_\alpha$

$$Q = \int dz \lambda^\alpha d_\alpha$$

$$d_\alpha = p_\alpha + \theta^\beta \chi_{\beta\alpha}, (\partial \bar{\lambda}^{\dot{\alpha}} \chi_{\alpha\dot{\alpha}})$$

$$\hat{Q} = \int d\bar{z} \hat{\lambda}^{\dot{\alpha}} \hat{d}_{\dot{\alpha}}$$

$$\hat{d}_{\dot{\alpha}} = \hat{p}_{\dot{\alpha}} + \hat{\theta}^{\beta\dot{\beta}} \hat{\chi}_{\beta\dot{\beta}\dot{\alpha}}, \frac{1}{y-2} \pi^{\dot{\alpha}\beta} \chi_{\beta\dot{\alpha}}$$

Open string

massless

$$V = \lambda^\alpha A_\alpha(x, \theta)$$

$$+ (\omega \lambda) A_\alpha$$

$$\pi^{\dot{\alpha}\beta} = \partial X^\beta + \theta^\gamma \chi^\beta_{\gamma\dot{\alpha}}$$

massive

$$V = \lambda^\alpha \left( \partial \theta^{\dot{\beta}} A_{\dot{\beta}\alpha}^{(p)} + \pi^{\dot{\beta}\gamma} A_{\dot{\beta}\gamma\alpha} + d_{\dot{\beta}\gamma} A_{\dot{\beta}\gamma\alpha} + (\omega \chi_{\dot{\beta}\gamma}) A_{\dot{\beta}\gamma\alpha} \right) + \partial \lambda^{\dot{\alpha}} \tilde{A}_{\dot{\alpha}}, \quad QV=0 \rightarrow \text{massive spin } \frac{1}{2} \text{ multiplet}$$

$$g(x, \theta, \hat{\theta}) \in \frac{PSU(2, 2|4)}{SO(4, 1) \times U(1)}$$

$$J = (g^{-1} \partial g)^\wedge$$

$$\bar{J} = (g^{-1} \bar{\partial} g)^\wedge$$

$$A \in PSU(2, 2|4)$$

$$a = 0 \dots 9$$

$$x = 1 \dots 16$$

$$y = 1 \dots 16$$

$$(ab) \in SO(4, 1) \times SO(5)$$

$$g(x, p, \hat{g}) \in \frac{PSU(2, 2|4)}{SO(4, 1) \times SO(5)}$$

$$J = (g^{-1} \partial g)^\wedge$$

$$\bar{J} = (g^{-1} \bar{\partial} g)^\wedge$$

$$A \in PSU(2, 2|4)$$

$$a = 0 \dots 9$$

$$x = 1 \dots 16$$

$$z = 1 \dots 16$$

$$(ab) \in SO(4, 1) \times SO(5)$$

$$g(x, \theta, \hat{\theta}) \in \frac{PSU(2, 2|4)}{SO(4, 1) \times SO(5)}$$

$$J = (g^{-1} \partial g)^{\wedge}$$
$$\bar{J} = (g^{-1} \bar{\partial} g)^{\wedge}$$

$$A \in PSU(2, 2|4)$$

$$a = 0 \dots 9$$

$$k = 1 \dots 14$$

$$l = 1 \dots 16$$

$$(ab) \in SO(4, 1) \times SO(5)$$

$$\gamma^A \partial_M$$

$$g(x, \theta, \hat{\theta}) \in \frac{PSU(2, 2|4)}{SO(4, 1) \times SO(5)}$$

$$J = (g^{-1} \partial g)^\wedge$$

$$\bar{J} = (g^{-1} \bar{\partial} g)^\wedge$$

$$A \in PSU(2, 2|4)$$

$$a = 0 \dots 9$$

$$K = 1 \dots 16$$

$$\bar{K} = 1 \dots 16$$

$$(ab) \in SO(4, 1) \times SO(5)$$

$$J^A = E^A_M \partial Y^M$$

$$A = \mu, 2, a$$

$$J^{(ab)} = \Omega^{(ab)}_M \partial Y^M$$

$$g(x, \theta, \hat{\theta}) \in \frac{PSU(2, 2|4)}{SO(4, 1) \times SO(5)}$$

$$J = (g^{-1} \partial g)^\wedge$$

$$\bar{J} = (g^{-1} \bar{\partial} g)^\wedge$$

$$A \in PSU(2, 2|4)$$

$$\alpha = 0, \dots, 9$$

$$\beta = 1, \dots, 16$$

$$\gamma = 1, \dots, 16$$

$$(a, b) \in SO(4, 1) \times SO(5)$$

$$J^\wedge = E_M^\wedge \partial Y^M \quad A = \alpha, \beta, \gamma$$

$$J^{(a)} = \Omega_M^{(a)} \partial Y^M$$

$$F^{\alpha\beta} = \delta^{\alpha\beta} = (\delta^{01234})^{\alpha\beta}$$

$$S_{\omega_2} = \Lambda_n(\gamma^m) \alpha \rightarrow (\omega \gamma^m) \alpha, \omega \gamma^m \alpha$$

$$\begin{aligned}
 S = \int d^2z \left( T^{\alpha} \bar{T}^{\alpha} + \delta_{\alpha\beta} (T^{\alpha} \bar{T}^{\beta} - \bar{T}^{\alpha} T^{\beta}) \right) \\
 + \bar{T}^{\alpha} d_{\alpha} + T^{\beta} \bar{d}_{\beta} + \delta^{\alpha\beta} d_{\alpha} d_{\beta} \\
 +
 \end{aligned}$$

$$S = \int d^2z \left( \mathcal{J}^a \bar{\mathcal{J}}^a + \int_{\mathbb{R}^2} (\mathcal{J}^{\mu} \bar{\mathcal{J}}^{\nu} - \bar{\mathcal{J}}^{\mu} \mathcal{J}^{\nu}) \right)$$

$$+ \bar{\mathcal{J}}^{\mu} d_{\mu} d_2 + \int_{\mathbb{R}^2} d_{\mu} d_2$$

+

$$\int d^2z dt \left( \right)$$



$$\begin{aligned}
S = \int d^2z & \left( T^{\alpha} \bar{T}^{\alpha} + \gamma_{\alpha\beta} (T^{\alpha} \bar{T}^{\beta} - \bar{T}^{\alpha} T^{\beta}) \right) \\
& + \bar{T}^{\alpha} d_{\alpha} + T^{\beta} \bar{d}_{\beta} + \delta^{\alpha\beta} d_{\alpha} d_{\beta} \\
& + \int d^2z dt \left( \right)
\end{aligned}$$

$$S = \int d^2z \left( T^A \bar{T}^A + \gamma_{\alpha\beta} (T^\alpha \bar{T}^\beta - \bar{T}^\alpha T^\beta) \right. \\
\left. + \bar{T}^\alpha d_\alpha + T^{\hat{\alpha}} \hat{d}_{\hat{\alpha}} + \delta^{\alpha\beta} d_\alpha d_\beta \right)$$

+



$$\begin{aligned}
S = \int d^2z & \left( T^A \bar{T}^A + \gamma_{\alpha\beta} (T^\alpha \bar{T}^\beta - \bar{T}^\alpha T^\beta) \right) \\
& + \bar{T}^\alpha d_\alpha + T^{\hat{\alpha}} \hat{d}_{\hat{\alpha}} + \delta^{\alpha\beta} d_\alpha d_\beta \\
& + \hat{d}_\alpha (\omega\gamma\lambda) + \text{[scribbled out]} (\omega\gamma\lambda)(\bar{\omega}\gamma\bar{\lambda})
\end{aligned}$$

$$Y^M = (x^m, \theta^{\alpha}, \bar{\theta}^{\dot{\alpha}})$$

$$= \frac{\partial \mathcal{L}}{\partial(\theta^{\alpha})}$$

$$\begin{aligned}
 & + \Omega^{ab} d_z(\hat{\omega}\gamma_{ab}\hat{\lambda}) + \hat{\Omega}_m{}^{ab}(\hat{\omega}\gamma_{ab}\hat{\lambda})\bar{\partial}Y^m \\
 & + \hat{\Omega}^{ab} d_z(\hat{\omega}\gamma_{ab}\hat{\lambda}) + \hat{\Omega}^{ab}(\hat{\omega}\gamma_{ab}\hat{\lambda})\hat{d}_z + R^{abcd}(\hat{\omega}\gamma_{ab}\hat{\lambda})(\hat{\omega}\gamma_{cd}\hat{\lambda}) \\
 & + \omega\bar{\partial}\hat{\lambda} + \hat{\omega}\partial\hat{\lambda} + \alpha' \int d^2z \varphi(x, \theta, \bar{\theta}) \mathcal{R}
 \end{aligned}$$

$$\int d^2z (A_m \partial X^m + F_{mn} \Psi^m \Psi^n)$$

$$N^{mn} = \Psi^m \Psi^n$$

$$N^{mn} N^{mn} \rightarrow \frac{d!}{(d-1)!}$$

$$\int d^2z d^2\bar{z} (g_{mn} + b_{mn}) \partial X^m \bar{\partial} X^n$$

$$N_1 + N_2$$

$$\begin{aligned} k_1 &= +4 \\ k_2 &= -3 \end{aligned}$$

$$+ \omega_m{}^{ab} \partial X^m \hat{\Psi}_a \hat{\Psi}_b + \hat{\omega}_m{}^{ab} \Psi_a \Psi_b \bar{\partial} X^m$$

(2)

$$+ \alpha' \int d^2z d^2\bar{z} \varphi \mathcal{R}$$

$$+ R_{abcd} \Psi^a \Psi^b \bar{\Psi}^c \bar{\Psi}^d$$

$$S = \int d^2z \left( J^a \bar{J}^a + \gamma_{\alpha\beta} (J^\alpha \bar{J}^\beta - \bar{J}^\alpha J^\beta) \right)$$

$$+ d_\alpha + J^\alpha \bar{d}_\alpha + \delta^{\alpha\beta} d_\alpha d_\beta$$

$$\hat{d}_\alpha(\omega\gamma\lambda)$$

+

~~$$+ (\omega\gamma\lambda)(\bar{\omega}\bar{\gamma}\bar{\lambda}) + \omega\bar{\omega}\lambda + \bar{\omega}\omega\bar{\lambda}$$~~

$$S = \int d^2z \left( T^{\alpha} \bar{T}^{\alpha} + \gamma_{\alpha\beta} (T^{\alpha} \bar{T}^{\beta} - \bar{T}^{\alpha} T^{\beta}) \right)$$

$$d_1 + T^{\hat{2}} \bar{d}_2 + \delta^{\alpha\beta} d_{\alpha} \bar{d}_{\beta}$$

$$\hat{d}_1(\omega\gamma\lambda) + (\omega\gamma\lambda)(\bar{\omega}\bar{\gamma}\bar{\lambda}) + \omega\bar{\omega}\lambda + \bar{\omega}\omega\bar{\lambda}$$

$$\begin{aligned}
 S = \int d^2z & \left( T^{\alpha} \bar{T}^{\alpha} + \gamma_{\alpha\beta} (T^{\alpha} \bar{T}^{\beta} - \bar{T}^{\alpha} T^{\beta}) \right) \\
 & + \bar{T}^{\alpha} d_{\alpha} + T^{\alpha} \bar{d}_{\alpha} + \delta^{\alpha\beta} d_{\alpha} \bar{d}_{\beta} \\
 & + \hat{d}_{\alpha}(\omega\gamma\lambda) + \hat{d}_{\alpha}(\omega\gamma\bar{\lambda}) + \omega\partial_{\alpha}\lambda + \bar{\omega}\partial_{\alpha}\bar{\lambda}
 \end{aligned}$$

$$\int d^2z \left( T^{\alpha} \bar{T}^{\alpha} + \gamma_{\alpha\beta} \left( \frac{3}{4} T^{\alpha} \bar{T}^{\beta} - \frac{1}{4} \bar{T}^{\alpha} T^{\beta} \right) \right)$$

$$\begin{aligned}
S &= \int d^2z \left( T^{\alpha} \bar{T}^{\alpha} + \delta_{\alpha\beta} (T^{\alpha} \bar{T}^{\beta} - \bar{T}^{\alpha} T^{\beta}) \right. \\
&\quad + \bar{T}^{\alpha} d_{\alpha} + T^{\beta} \bar{d}_{\beta} + \delta^{\alpha\beta} d_{\alpha} \hat{d}_{\beta} \\
&\quad \left. + \hat{d}_{\alpha} (\omega \gamma^{\alpha}) + \cancel{(\omega \gamma^{\alpha}) (\bar{\omega} \gamma^{\alpha})} + \omega \bar{\omega} \lambda + \bar{\omega} \omega \bar{\lambda} \right) \\
&= \int d^2z \left( T^{\alpha} \bar{T}^{\alpha} + \delta_{\alpha\beta} \left( \frac{3}{4} T^{\alpha} \bar{T}^{\beta} - \frac{1}{4} \bar{T}^{\alpha} T^{\beta} \right) \right. \\
&\quad \left. + \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \bar{\lambda} + (\omega \gamma^{\alpha}) (\bar{\omega} \gamma^{\alpha}) \bar{\lambda} \right)
\end{aligned}$$



$$\begin{aligned}
S &= \int d^2z \left( T^a \bar{T}^a + \delta_{\alpha\beta} (T^\alpha \bar{T}^\beta - \bar{T}^\alpha T^\beta) \right. \\
&\quad + \bar{T}^\alpha d_\alpha + T^\beta \bar{d}_\beta + \delta^{\alpha\beta} d_\alpha \bar{d}_\beta \\
&\quad \left. + \hat{d}_\alpha (\omega \gamma^\alpha) + \text{[scribbled out]} (\omega \gamma^\alpha) (\bar{\omega} \gamma^\alpha) + \omega \bar{\partial} \lambda + \bar{\omega} \partial \bar{\lambda} \right) \\
&= \int d^2z \left( T^a \bar{T}^a + \delta_{\alpha\beta} \left( \frac{3}{4} T^\alpha \bar{T}^\beta - \frac{1}{4} \bar{T}^\alpha T^\beta \right) \right. \\
&\quad \left. + \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \bar{\lambda} + (\omega \gamma^{\alpha\beta}) (\bar{\omega} \gamma^{\alpha\beta}) \right) \\
&\quad \bar{\nabla} \lambda = \bar{\partial} \lambda + T^{\alpha\beta} (\gamma^{\alpha\beta}) \lambda
\end{aligned}$$

$$\lambda^{\mu} \bar{J}^{\nu} \lambda^{\rho}$$

$$\lambda^{\mu} \bar{J}^{\nu} \lambda^{\rho}$$

$$+ \bar{J}^{\mu} d_{\mu} + J^{\nu} \bar{d}_{\nu} + \delta^{\mu\nu} d_{\mu} \bar{d}_{\nu}$$

$$+ \hat{d}_{\mu} (\omega^{\mu\nu} \lambda^{\nu}) + (\omega^{\mu\nu} \lambda^{\nu}) (\omega^{\mu\rho} \bar{\lambda}^{\rho}) + \omega^{\mu\nu} \lambda^{\nu} + \omega^{\mu\rho} \bar{\lambda}^{\rho}$$

$$\sum = d_{\mu}^2 \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} \left( \frac{3}{4} J^{\mu} \bar{J}^{\nu} - \frac{1}{4} \bar{J}^{\mu} J^{\nu} \right) \right.$$

$$\left. + \omega^{\mu\nu} \lambda^{\nu} + \omega^{\mu\rho} \bar{\lambda}^{\rho} + (\omega^{\mu\nu} \lambda^{\nu}) (\omega^{\mu\rho} \bar{\lambda}^{\rho}) \right)$$

$$\bar{\nabla} \lambda^{\mu} = \partial \lambda^{\mu} + J^{\nu} (\omega^{\mu\nu} \lambda^{\nu})$$

$$S = \int d^2z \left( J^a \bar{J}^a + \delta_{\mu 2} (J^\mu \bar{J}^2 - \bar{J}^\mu J^2) \right)$$

$$+ \bar{J}^\mu d_\mu + J^2 \bar{d}_2 + \delta^{\mu 2} d_\mu \hat{d}_2$$

$$+ \hat{d}_2 (\omega \gamma \lambda) + (\omega \gamma \lambda) (\bar{\omega} \gamma \bar{\lambda}) + \omega \bar{\partial} \lambda + \bar{\omega} \partial \bar{\lambda}$$

$$\boxed{\begin{aligned} Q &= \int d^2z \lambda^{\mu\nu} \partial_\mu \bar{\lambda}_\nu \\ \bar{Q} &= \int d^2z \bar{\lambda}^{\mu\nu} \partial_\mu \lambda_\nu \end{aligned}}$$

$$\int d^2z \left( J^a \bar{J}^a + \delta_{\mu 2} \left( \frac{3}{4} J^\mu \bar{J}^2 - \frac{1}{4} \bar{J}^\mu J^2 \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \bar{\lambda} + (\omega \gamma^{\mu\nu} \lambda) (\bar{\omega} \gamma^{\mu\nu} \bar{\lambda})$$

$$\bar{\nabla} \lambda^{\mu\nu} = \bar{\partial} \lambda^{\mu\nu} + J^{\mu\nu} \gamma^{\mu\nu} \lambda^{\mu\nu}$$

$$S = \int d^2z \left( J^a \bar{J}^a + \delta_{\mu 2} (J^\mu \bar{J}^2 - \bar{J}^\mu J^2) \right)$$

$$+ \bar{J}^\mu d_\mu + J^2 \bar{d}_2 + \delta^{\mu 2} d_\mu \hat{d}_2$$

$$+ \Omega_{\mu\nu} \bar{\partial}_\mu \hat{\gamma}_\nu^{\mu\nu} +$$

$$+ (\omega \gamma_\mu) (\bar{\omega} \gamma^\mu) + \omega \bar{\partial} \lambda + \bar{\omega} \partial \lambda$$

$$\begin{aligned} Q &= \int d^2z \lambda^\mu J^2 \delta_{\mu 2} \\ \bar{Q} &= \int d^2z \hat{\lambda}^\mu \bar{J}^2 \delta_{\mu 2} \end{aligned}$$

$$S = \int d^2z \left( J^a \bar{J}^a + \delta_{\mu 2} \left( \frac{3}{4} J^\mu \bar{J}^2 - \frac{1}{4} \bar{J}^\mu J^2 \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \hat{\lambda} + (\omega \gamma^\mu \lambda) (\bar{\omega} \gamma_\mu \hat{\lambda})$$

$$\bar{\nabla} \lambda^\mu = \bar{\partial} \lambda^\mu + J^{\mu\nu} \gamma_{\nu\lambda}^\mu$$

$$V = \sum_{\lambda} \hat{\lambda}^2 A_{\lambda^2}(x, \theta, \hat{\theta})$$

$$V = \lambda^2 \hat{\lambda}^2 A_{\kappa 2} (x, \theta, \hat{\theta})$$

$$Q = \lambda^{\kappa} D_{\kappa} \rightarrow \lambda^{\kappa} \nabla_{\kappa}$$

$$E_{\kappa} = \frac{\partial}{\partial y^{\mu}} + \omega_{\kappa}^{\mu} M_{\mu\nu}$$

$$QV=0 \rightarrow \nabla_{\kappa} A_{p \kappa} (\gamma^{\mu\nu})^{\kappa p} = 0$$

$$V = \lambda \hat{\lambda}^2 A_{x^2}(x, \theta, \hat{\theta})$$

$$Q = \lambda \frac{\partial}{\partial x} \rightarrow \lambda \frac{\partial}{\partial x} \quad E = \frac{\partial}{\partial y} + \omega_n M_{xy}$$

$$QV=0 \rightarrow \nabla_x A_{p^2}(\gamma^{(1)}) = 0 \rightarrow A_{p^2}(\gamma^{(1)}) = 0$$

$$V = \lambda \hat{\lambda}^2 A_{\times 2}(x, \theta, \hat{\theta})$$

$$Q = \lambda \overset{\rightarrow}{D}_x \rightarrow \lambda \nabla_x$$

$\frac{\partial}{\partial x} (0 \cdot 0) \frac{\partial}{\partial x}$

$E_x \text{ с } \omega_n \text{ и } \lambda$

$$QV = 0 \rightarrow \nabla_x A_{p \times 2}(\gamma^{(1)})^{\times p} = 0 \rightarrow$$



$$g(x, \theta) \in \frac{PSU(2, 2|1)}{SO(4, 1) \times SO(5)}$$

$$J = \left( \begin{array}{c|c} g & \partial g \end{array} \right)$$

$$\bar{J} = \left( \begin{array}{c|c} \bar{g} & \partial \bar{g} \end{array} \right)^{\wedge}$$

$$A \in PSU(2, 2|1)$$

$$a = 0, 1, 2$$

$$\lambda = 1, 2, 3, 4$$

$$\lambda = 1, 2, 3, 4$$

$$(ab) \in SO(4, 1) \times SO(5)$$

$$J^{\wedge} = E^{\wedge}_M \partial Y^M$$

$$A = 1, 2, 3, 4$$

$$J^{(ab)} = \Omega^{\wedge}_{ab} \partial Y^M$$

$$F^{\wedge 2} = \delta^{\wedge 2} = (\delta^{01234})^{\wedge 2}$$

$$Q = \int d^2 x \lambda \bar{J} \delta_{\lambda 2}$$

$$S = \int d^2 x$$

$$\delta_{\lambda 2} \left( \frac{3}{4} J^{\wedge} \bar{J}^{\wedge 2} - \frac{1}{4} \bar{J}^{\wedge} J^{\wedge 2} \right)$$

$$+ \left( \omega \delta^{\wedge 2} \lambda + (\omega \delta^{\wedge 2} \lambda) (\omega Y^{\wedge 2} \lambda) \right)$$

$$V = \int \hat{\lambda}^2 A_{\lambda^2}(x, \theta, \hat{\theta})$$

$$Q = \int D_{\lambda} \rightarrow \int \nabla_{\lambda}$$

$$\frac{\partial}{\partial \lambda} \left( \frac{\partial}{\partial \lambda} \right) \frac{\partial}{\partial x_i}$$

$$F_{\lambda} \frac{\partial}{\partial y^{\mu}} + \omega_{\lambda}^{ab} M_{ab}$$

$$QV=0 \rightarrow \nabla_{\lambda} A_{\lambda^2}(\gamma^{ab}) = 0 \rightarrow A_{\lambda^2} \gamma^{ab}$$

$$V = \int \int A_{\alpha\beta}(\mathbf{x}, \boldsymbol{\theta}, \hat{\boldsymbol{\theta}})$$

$$Q = \int D_{\alpha} \rightarrow \int \nabla_{\alpha} \left( \frac{\partial \mathcal{L}}{\partial y^{\mu}} + \omega_{\alpha}^{\nu} M_{\nu\beta} \right)$$

$$QV=0 \rightarrow \nabla_{\alpha} A_{\beta\gamma}(\gamma) = 0 \rightarrow A_{\alpha\beta} \int \dots$$

$$V = \lambda \hat{\lambda}^2 A_{\lambda\lambda}(x, \theta, \hat{\theta})$$

$$D_{\lambda} \rightarrow \lambda \nabla_{\lambda} = \frac{\partial}{\partial \lambda} + \theta^{\mu} \frac{\partial}{\partial x^{\mu}} + \omega_{\lambda}^{ab} M_{ab}$$

$$QV=0 \rightarrow \nabla_{\lambda} A_{\beta\lambda}(\gamma^{\mu\nu\rho\sigma}) = 0 \rightarrow A_{\beta\lambda} \gamma^{\mu\nu\rho\sigma}$$

$$S = \int d^2z \left( J^a \bar{J}^a + \delta_{1,2} (J^1 \bar{J}^2 - \bar{J}^1 J^2) \right)$$

$$\begin{aligned} Q &= \int d_1 \lambda^1 J^2 \delta_{1,2} \\ \bar{Q} &= \int d_2 \bar{\lambda}^2 \bar{J}^1 \delta_{1,2} \end{aligned}$$

$$+ \bar{J}^1 d_1 + J^2 d_2 + \delta^{1,2} d_1 d_2 + \Omega^{\mu\nu} \partial_\mu (\omega \gamma_\nu) + \dots + (\omega \gamma_\mu) (\bar{\omega} \gamma^\mu) + \omega \partial_1 \lambda + \bar{\omega} \partial_2 \bar{\lambda}$$

$$S = \int d^2z \left( J^a \bar{J}^a + \delta_{1,2} \left( \frac{3}{4} J^1 \bar{J}^2 - \frac{1}{4} \bar{J}^1 J^2 \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \hat{\lambda} + (\omega \gamma^{(\mu\nu)} \lambda) (\bar{\omega} \gamma_{(\mu\nu)} \bar{\lambda}))$$

$$\bar{\nabla} \lambda^a = \partial \lambda^a + J^{(\mu\nu)} \gamma^{(a)} \lambda^b$$

$$S = R \int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} (J^{\nu} \bar{J}^{\mu} - \bar{J}^{\nu} J^{\mu}) \right)$$

$$+ \bar{J}^{\mu} d_{\mu} + J^{\mu} \bar{d}_{\mu} + \delta^{\mu\nu} d_{\mu} \bar{d}_{\nu}$$

$$+ \partial_{\mu}^{\nu} \bar{\psi}^{\mu} (\omega \psi^{\nu}) + \partial_{\mu}^{\nu} (\omega \psi^{\mu}) \bar{\psi}^{\nu} + \omega \bar{\psi}^{\mu} \psi^{\mu} + \omega \psi^{\mu} \bar{\psi}^{\mu}$$

$$\boxed{Q = \int d_1 \lambda$$

$$\bar{Q} = \int d_2 \bar{\lambda}}$$

$$\int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} \left( \frac{3}{4} J^{\nu} \bar{J}^{\mu} - \frac{1}{4} \bar{J}^{\nu} J^{\mu} \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \omega \nabla \bar{\lambda} + (\omega \psi^{\mu}) (\omega \psi^{\mu}) \bar{\lambda} \lambda$$

$$\bar{\nabla} \lambda = \bar{\partial} \lambda + J^{\mu} \psi^{\mu} \lambda$$

$$V = \lambda \hat{\lambda}^2 A_{\kappa 2}(x, \theta, \hat{\theta})$$

$$J^* J^*$$

$$\{ J^* J^* \}$$

$$F^{\mu\nu} = \delta^{\mu\nu} = (\delta^{01234})_{\mu\nu}$$

Qg

$$Q = \int d^4x \lambda \bar{J}^{\mu\nu} \delta_{\mu\nu}$$

$$\bar{Q} = \int d^4z \bar{\lambda}^{\mu\nu} \bar{J}^{\mu\nu} \delta_{\mu\nu}$$

$$S = \int d^4z \left( J^{\mu\nu} \bar{J}^{\mu\nu} - \frac{1}{4} \bar{J}^{\mu\nu} J^{\mu\nu} \right)$$

$$+ \omega \nabla_{\mu} \left( \bar{J}^{\mu\nu} J^{\mu\nu} \right)$$



$so(4,1)$

$A \in PSU(2,2|1)$

$$J^A = E^A_M \partial Y^M$$

$A = 0, 2, \alpha$

$$J^{(ab)} = \Omega^{(ab)} \partial Y^M$$

$$F^{\alpha\beta} = \delta^{\alpha\beta} = (\delta^{02})_{\alpha\beta}$$

$$J = \left( g^{-1} \frac{\partial}{\partial g} \right)^A$$

$$a = 0, 1, 2$$

$$\lambda = 1, 2$$

$$\mu = 1, 2$$

$(ab) \in so(4,1), so(5)$

global  $so(4,1)$

$$g \rightarrow \sum g$$

local  $so(4,1) \sim so(5)$

$$g \rightarrow g \Omega$$

$$\Omega g \rightarrow g$$

$$Q = \int d^4x \lambda \dots$$

$$\bar{Q} = \int d^4x \bar{\lambda} \dots$$

$S$

$$+ \int d^4x \left( \frac{3}{4} J^{\alpha\beta} \bar{J}^{\alpha\beta} - \frac{1}{4} \bar{J}^{\alpha\beta} J^{\alpha\beta} \right)$$

$$\left( \omega \bar{\nabla} \lambda + \omega \nabla \bar{\lambda} + (\omega \delta^{\alpha\beta}) (\bar{\omega} \gamma^{\alpha\beta}) \lambda \right)$$

$$\bar{\nabla} \lambda = \partial \lambda + J^{\alpha\beta} \gamma^{\alpha\beta} \lambda$$

$$J^{(a)} = \Omega^{(a)} \partial \gamma$$

$$F^{(a)} = \delta^{(a)} = (\delta^{01234})$$

(a,b)  $\in$   $SO(4,1), SO(5)$

global  
rule, (114)

$$g \rightarrow \sum g$$

local  $SO(4,1) \rightarrow SO(5)$

$$g \rightarrow g \Omega$$

$$Q g = g (\lambda^{\mu} T_{\mu} + \hat{\lambda}^{\mu} T_{\mu})$$

Fermionic  $PSU(2,2|1)$

$$S = \frac{K^2}{\omega^2} \int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} (J^{\mu} \bar{J}^{\nu} - \bar{J}^{\mu} J^{\nu}) \right)$$

$$+ \bar{J}^{\mu} d_{\mu} + J^{\mu} \bar{d}_{\mu} + \delta^{\mu\nu} d_{\mu} \bar{d}_{\nu}$$

$$\begin{aligned} Q \cdot \int d^2z \lambda^{\mu} J^{\mu} \delta_{\mu\nu} \\ \bar{Q} \cdot \int d^2z \hat{\lambda}^{\mu} \bar{J}^{\mu} \delta_{\mu\nu} \end{aligned}$$

$$+ \Omega^{\mu\nu} \partial_{\mu} \lambda^{\nu} + (\omega \partial_{\mu} \lambda^{\mu}) + (\omega \partial_{\mu} \hat{\lambda}^{\mu}) + \omega \partial_{\mu} \lambda^{\mu} + \omega \partial_{\mu} \hat{\lambda}^{\mu}$$

$$S = \int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} \left( \frac{3}{4} J^{\mu} \bar{J}^{\nu} - \frac{1}{4} \bar{J}^{\mu} J^{\nu} \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \omega \nabla \hat{\lambda} + (\omega \delta^{\mu\nu} \lambda^{\mu} \omega \gamma^{\mu\nu} \hat{\lambda}^{\nu})$$

$$\bar{\nabla} \lambda = \partial \lambda + J^{\mu\nu} \gamma^{\mu\nu} \lambda$$

$$V = \lambda \hat{\lambda}^2 A_{k2}(x, \theta, \hat{\theta})$$

$$\cdot J^* \bar{J}^*$$

$$\cdot \delta_{k2} J^* \bar{J}^*$$

$$\cdot \delta_{k2} \bar{J}^* J^*$$

$$QS = 0$$

$$\delta S = Q\Omega$$

$\Rightarrow$  fixes cubic up to small constant

$$V = \lambda \hat{\lambda}^2 A_{x,2}(x, \theta, \hat{\theta})$$

$$\bullet J^* \bar{J}^*$$

$$\bullet \delta_{x,2} J^* \bar{J}^*$$

$$\bullet \delta_{x,2} \bar{J}^* J^*$$

$$QS = 0$$

$$\delta S = Q\Omega$$

$\Rightarrow$  fixes cubic up to small constant

$$V = \lambda \hat{\lambda}^2 A_{x,2}(x, \theta, \hat{\theta})$$

$$\begin{cases} \cdot J^* \bar{J}^* \\ \cdot \delta_{x,2} J^* \bar{J}^* \\ \cdot \delta_{x,2} \bar{J}^* J^* \end{cases}$$

$$\begin{aligned} QS &= 0 \\ \delta S &= Q\Omega \end{aligned}$$

$\Rightarrow$  fixes cubic up to small constant

$$J^{(ab)} = \Omega^{(ab)} \partial \gamma$$

$$F^{(ab)} = \delta^{(ab)} = (\delta^{01234}) \dots$$

(ab) ∈ So(4,1), So(5)

global rule (214)

$$g \rightarrow \sum g$$

local So(4,1) = So(5)

$$g \rightarrow g \Omega$$

$$Q g = g (\lambda^{\mu} T_{\mu} + \hat{\lambda}^{\mu} T_{\mu})$$

Fermionic (PSU(2,2|1))

$$S = \frac{K}{2\pi} \int dz \left( J^{\mu} \bar{J}^{\mu} + \gamma_{\mu\nu} (J^{\mu} \bar{J}^{\nu} - \bar{J}^{\mu} J^{\nu}) \right)$$

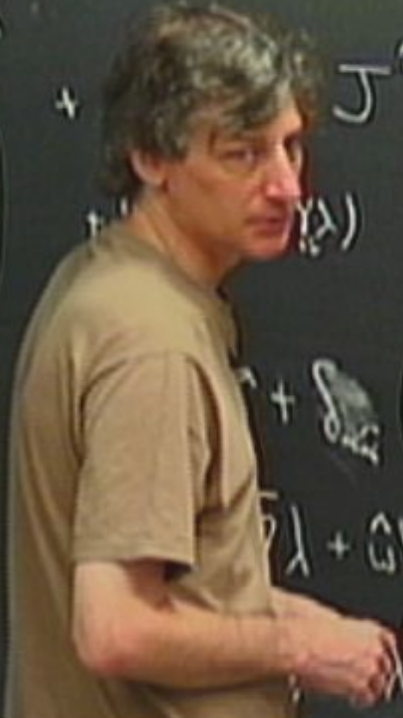
$$+ J^{\mu} \bar{d}_{\mu} + \delta^{\mu\nu} d_{\mu} \hat{d}_{\nu}$$

$$\begin{aligned} Q &= \int dz \lambda^{\mu} J^{\mu} \delta_{\mu 2} \\ \bar{Q} &= \int dz \hat{\lambda}^{\mu} \bar{J}^{\mu} \delta_{\mu 2} \end{aligned}$$

$$S = \int dz \dots$$

$$+ \delta_{\mu\nu} \left( \frac{3}{4} J^{\mu} \bar{J}^{\nu} - \frac{1}{4} \bar{J}^{\mu} J^{\nu} \right)$$

$$\left( \partial \lambda + \omega \nabla \lambda + (\omega \delta^{\mu\nu}) (\omega \gamma^{\mu\nu}) \lambda \right)$$



$$J^{(A)} = \Omega^{(A)} \partial \gamma$$

$$F^{(A)} = \delta^{(A)} = (\delta^{01234})$$

(a,b)  $\in$   $SO(4,1), SO(5)$

global  
rule, (14)

$$g \rightarrow \sum g$$

local soln.  $\rightarrow$   $SO(5)$

$$g \rightarrow g \Omega$$

$$Q g = g (\lambda^1 T_1 + \lambda^2 T_2)$$

Fermionic  $PSU(2,2|1)$

$$S = \frac{K^2}{2\pi} \int d^2 z \left( J^+ \bar{J}^+ + \delta_{+2} (J^- \bar{J}^- - \bar{J}^- J^+) \right)$$

$$+ \bar{J}^+ d_{+1} + J^2 \bar{d}_{+2} + \delta^{+2} d_{+1} \bar{d}_{+2}$$

$$+ \Omega^{(A)} \partial \gamma^{(A)} + \dots + (\omega \partial \lambda + \bar{\omega} \partial \bar{\lambda})$$

$$\begin{aligned} Q \cdot \int d^2 z \lambda^+ J^2 \delta_{+2} \\ \bar{Q} \cdot \int d^2 z \bar{\lambda}^+ \bar{J}^+ \delta_{+2} \end{aligned}$$

$$S = \int d^2 z \left( J^+ \bar{J}^+ + \delta_{+2} \left( \frac{3}{4} J^- \bar{J}^- - \frac{1}{4} \bar{J}^- J^+ \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \bar{\lambda} + (\omega \delta^{(A)} \lambda) (\bar{\omega} \gamma^{(A)} \bar{\lambda})$$

$$\bar{\nabla} \lambda = \partial \lambda + J^{(A)} \gamma^{(A)} \lambda$$

$$J^{(ab)} = \Omega^{(ab)} \partial \gamma$$

$$F^{(ab)} = \delta^{(ab)} = (\delta^{01234})$$

(ab)  $\in$   $SO(4,1), SO(5)$

global  
rule, (114)

$$g \rightarrow \sum g$$

local  $SO(4,1) \sim SO(5)$

$$g \rightarrow g \Omega$$

$$Q g = g (\lambda^{\mu} T_{\mu} + \hat{\lambda}^{\mu} T_{\mu})$$

Fermionic  $PSU(2,2|1)$

$$S = \frac{K^2}{\omega^2} \int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} (J^{\mu} \bar{J}^{\nu} - \bar{J}^{\mu} J^{\nu}) \right)$$

$$+ \bar{J}^{\mu} d_{\mu} + J^{\mu} \bar{d}_{\mu} + \delta^{\mu\nu} d_{\mu} \hat{d}_{\nu}$$

$$+ \Omega^{\mu\nu} \partial \gamma^{\mu} \partial \gamma^{\nu} + (\omega \gamma^{\mu}) (\omega \gamma^{\nu}) + \omega \partial \lambda$$

$$\begin{aligned} Q &= \int d^2z \lambda^{\mu} J^{\mu} \delta_{\mu\nu} \\ \bar{Q} &= \int d^2z \hat{\lambda}^{\mu} \bar{J}^{\mu} \delta_{\mu\nu} \end{aligned}$$

$$S = \int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} \left( \frac{3}{4} J^{\mu} \bar{J}^{\nu} - \frac{1}{4} \bar{J}^{\mu} J^{\nu} \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \omega \nabla \hat{\lambda} + (\omega \delta^{\mu\nu}) (\omega \gamma^{\mu\nu})$$

$$\bar{\nabla} \lambda = \partial \lambda + J^{\mu\nu} \gamma^{\mu\nu} \lambda$$



$$V = \lambda^2 \hat{\lambda}^2 A_{4,2}(x, \theta, \hat{\theta})$$

$$\begin{cases} a. J^* \bar{J}^1 \\ b. \delta_{4,2} J^* \bar{J}^2 \\ c. \delta_{4,2} \bar{J}^1 \cdot J^2 \end{cases}$$

$$\begin{aligned} QS &= 0 \\ \delta S &= Q\Omega \end{aligned} \Rightarrow \text{fixes cubic up to small constant}$$

$$\text{global } PSU(2,2|4) \rightarrow \int_0^1 ds \left( \dots \right)$$

$$+ \gamma_n (0 \ 0 \ 0) \dots$$

$$V = \lambda \hat{\lambda}^2 A_{4,2}(x, \theta, \hat{\theta})$$

$$\begin{cases} a \ J^* \bar{J}^1 \\ b \ \int_{\mathbb{R}^2} J^* \bar{J}^2 \\ c \ \int_{\mathbb{R}^2} \bar{J}^1 \cdot J^2 \end{cases}$$

$$\begin{aligned} QS &= 0 \\ \delta S &= Q\Omega \end{aligned} \Rightarrow \text{fixes cubic up to small constant}$$

$$\text{global } \mathbb{P}SU(2, 2) \rightarrow \int_0^1 \dots$$

$$V = \lambda^2 \hat{\lambda}^2 A_{4,2}(x, \theta, \hat{\theta})$$

$$\begin{cases} a & J^* \bar{J}^1 \\ b & \int_{\mathbb{R}^2} J^* \bar{J}^2 \\ c & \int_{\mathbb{R}^2} \bar{J}^1 \cdot J^2 \end{cases}$$

$$\begin{aligned} QS &= 0 \\ \delta S &= Q\Omega \end{aligned}$$

$\Rightarrow$  fixes cubic up to small constant

$$\text{global } \text{PSU}(2, 2|4) \rightarrow$$

$$\begin{aligned} \phi_1 &= \int_{\mathbb{R}^2} \dots \\ \phi_2 &= \int_{\mathbb{R}^2} \dots \end{aligned}$$

$$V = \lambda^2 \hat{\lambda}^2 A_{4,2}(x, \theta, \hat{\theta})$$

$$\begin{aligned} & \cdot J^* \bar{J}^* \\ & \cdot \delta_{\alpha\beta} J^* \bar{J}^{\beta} \\ & \cdot \delta_{\alpha\beta} \bar{J}^{\alpha} J^{\beta} \end{aligned}$$

$$QS = 0$$

$$\delta S = Q\Omega$$

$\Rightarrow$  fixes cubic  
up to small  
constant

$$g \text{ (h) } |PSU(2,2|4)| \rightarrow$$

do ?

$$\phi_1 = \int_{\Sigma} ds ( \quad )$$

$$J^{(A)} = \Omega^{(A)} \partial \gamma$$

$$F^{(2)} = \delta^{(2)} = (\delta^{01234567})$$

(a,b)  $\in$   $SO(4,1), SO(5)$

global  
rule, (1,1)

$$g \rightarrow \sum g$$

local  $SO(4,1) \rightarrow SU(2,1)$

$$g \rightarrow g \Omega$$

$$Q g = g (\lambda^{\mu} T_{\mu} + \hat{\lambda}^{\mu} T_{\mu})$$

fermionic  $PSU(2,2|1)$

$$S = \frac{K^2}{4\pi} \int d^2z \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} (J^{\mu} \bar{J}^{\nu} - \bar{J}^{\mu} J^{\nu}) \right)$$

$$\bar{J}^{\mu} d_{\mu} + J^{\mu} \bar{d}_{\mu} + \delta^{\mu\nu} d_{\mu} \bar{d}_{\nu}$$

$$Q = \int d_1 \lambda^{\mu} J^{\mu} \delta$$

$$\bar{Q} = \int d_2 \hat{\lambda}^{\mu} \bar{J}^{\mu} \delta$$

$$\left( \partial_1^{\mu} \bar{\partial}_2^{\nu} (\omega \lambda^{\mu}) + (\omega \lambda^{\mu}) (\bar{\omega} \bar{\lambda}^{\nu}) + \omega \bar{\omega} \lambda^{\mu} + \bar{\omega} \omega \bar{\lambda}^{\nu} \right)$$

$$S = \int \left( J^{\mu} \bar{J}^{\mu} + \delta_{\mu\nu} \left( \frac{3}{4} J^{\mu} \bar{J}^{\nu} - \frac{1}{4} \bar{J}^{\mu} J^{\nu} \right) \right)$$

$$+ \omega \bar{\nabla} \lambda + \bar{\omega} \nabla \hat{\lambda} + (\omega \delta^{\mu\nu} \lambda) (\bar{\omega} \gamma^{\mu\nu} \hat{\lambda})$$

$$\bar{\nabla} \lambda = \bar{\partial} \lambda + J^{\mu\nu} \gamma^{\mu\nu} \lambda$$

$$+ \gamma_n (0 \ 0) \dots (0 \ 0) \dots$$

$$V = \lambda \hat{\lambda}^2 A_{x^2}(x, \theta, \hat{\theta}) \rightarrow \text{Kerr surface}$$

$$\begin{cases} J^{\alpha} \bar{J}^{\beta} \\ \delta_{\alpha\beta} J^{\alpha} \bar{J}^{\beta} \\ \delta_{\alpha\beta} \bar{J}^{\alpha} J^{\beta} \end{cases}$$

$$\begin{aligned} QS &= 0 \\ \delta S &= Q\Omega \end{aligned} \Rightarrow \text{fixes cubic up to small constant}$$

$$g_{\text{flat}} |PSU(2, 2|4)| \rightarrow \int \dots$$

$$V = \int \hat{\lambda}^2 \Lambda(x, \theta, \hat{\theta})$$

→ Kohn-Superpace

$$\langle v_1, v_2, v_3 \rangle$$

⇒ fixes cubic up to small constant

$$\delta S = Q\Omega$$

global  $PSU(2, 2|4)$  →

do ?

$$dI = \int_{\mathcal{M}} \delta S(\dots)$$

$$+ \gamma_n (0 \ 0) \dots (0 \ 0) \dots$$

$$V = \lambda \hat{\lambda}^2 A_{x,2}(x, \theta, \hat{\theta}) \rightarrow \text{Kahler super space}$$

$$\begin{aligned} a & J^* \bar{J}^1 \\ b & \delta_{x,2} J^* \bar{J}^2 \\ c & \delta_{x,2} \bar{J}^1 J^2 \end{aligned}$$

$$\langle v_1, v_2, v_3 \rangle$$

$$\begin{aligned} QS = 0 & \Rightarrow \text{fixes cubic up to small constant} \\ \delta S = Q\Omega \end{aligned}$$

$$\text{global } PSU(2,2|4) \rightarrow \int \dots$$