$N=0$ Soft SUSY Breaking

SUSY cancels quadr. divergences
for scalar masses
put in supermultiplets with fermions

fermions have chiral symmetries

fermion masses are at most log. div.

fermion mass vanishes as bare mass $\to 0$

$$m_f = m_0 + \frac{\alpha}{16\pi^2} m_0 \ln\left(\frac{\Lambda}{m_0}\right) + \dots$$

SUSY must be broken
in the real world

lots of ways to do this

eg $\quad W = F^a \phi_a$

$\quad V = W_a^* W^a = F^{a*} F_a \neq 0$

dimensionless coupling need to
be related to cancel divergences

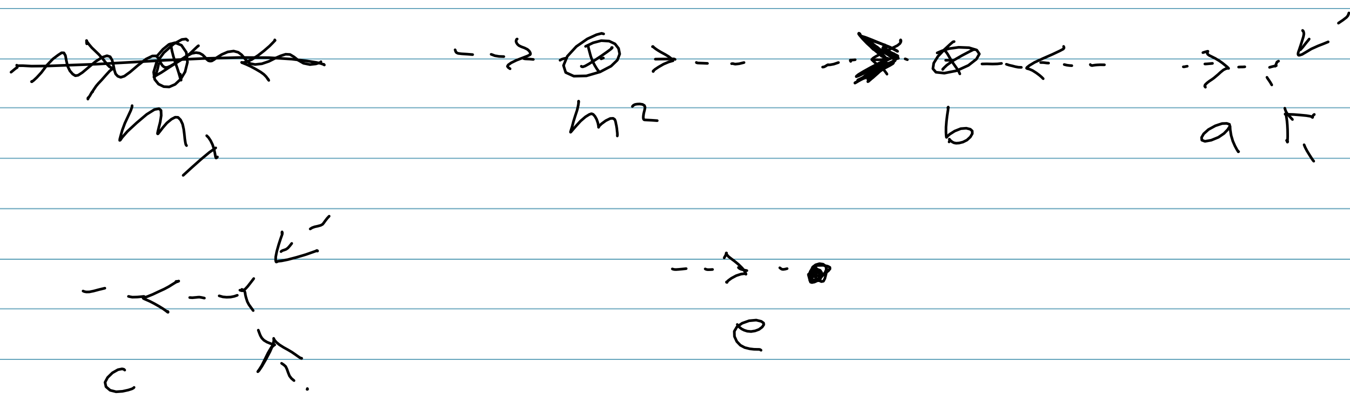
$$\delta m^2 \propto (\lambda - |y_t|^2)\, \Lambda^2$$

want effective theory spontaneously broken SUSY
with only soft breaking ($d_{im} < 4$) terms

$$\mathcal{L}_{soft} = -\frac{1}{2}\left(M_\lambda \lambda^a \lambda^a + h.c.\right) - (m^2)^i_j\, \phi^{*j} \phi_i$$
$$- \left(\frac{1}{2} b^{ij} \phi_i \phi_j + \frac{1}{6} a^{ijk} \phi_i \phi_j \phi_k + h.c.\right)$$
$$- \frac{1}{2} c_i^{\ jk} \phi^{*i} \phi_j \phi_k + h.c.$$
$$- e^i \phi_i + h.c.$$

only exist if ϕ_i is a gauge singlet

$c_i^{\ jk}$ can introduce Λ^2 divergence if $\exists$ a gauge singlet field



spontaneous $\cancel{\text{SUSY}}$ $\xRightarrow{\text{feed down}}$ superpartners

consistent SUSY theory

parameter $\to$ ⟨spurion field⟩

$$\int d^4\theta \, Z \, \Phi^\dagger \Phi$$

$$Z = 1 + \beta\theta^2 + \beta^*\bar{\theta}^2 + \gamma\,\theta^2\bar{\theta}^2$$

only scalar component have VEVs if we preserve Lorentz inv.

$$= \mathcal{L}_{\text{free WZ}} + \beta F^*\phi + \beta^*\phi^* F + \gamma\phi^*\phi$$

integrate out F

$$- \partial^\mu\phi^\dagger\partial_\mu\phi + i\psi^\dagger\bar{\sigma}^\mu\partial_\mu\psi + (\gamma - |\beta|^2)\phi^*\phi$$

soft breaking $m^2 = |\beta|^2 - \gamma$

can do the same for superpot. couplings

Yukawa ϕ^3 $\quad$ mass ϕ^2 $\quad$ $\tau W_\alpha W_\alpha$

$\downarrow$ $\quad$ $\downarrow$ $\quad$ $\downarrow$

a $\quad$ b $\quad$ m_λ

$$\int d^4\theta \; C_i^{jk}\, \Phi^{i\dagger}\Phi_j\Phi_k$$

$\hookrightarrow$ $\theta^2\bar{\theta}^2$ component nonvanishing

SUSY QCD

chiral superfields $Q_i = (\phi_i, Q_i, F_i)$, $Q_i^\dagger = (\phi_i^*, Q_i^\dagger, F_i^*)$

$\bar{Q}_i = (\bar{\phi}_i, \bar{Q}_i, \bar{F}_i)$

	$SU(N)$	$SU(F)$	$SU(F)$	$U(1)$	$U(1)_R$
Q	$\square$	$\square$	1	1	$\frac{F-N}{F}$
$\bar{Q}$	$\bar{\square}$	1	$\bar{\square}$	-1	$\frac{F-N}{F}$

$W = 0 \qquad [R, Q_\alpha] = -Q_\alpha \Rightarrow R_{Q} = R_\phi - 1$

$R\theta = +\theta$

$R\lambda^a = +\lambda^a$

$RW = +2W$

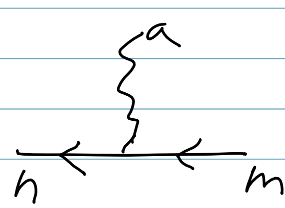
Group Theory

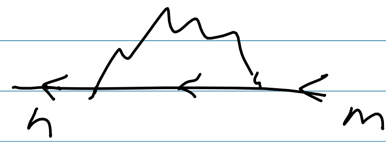
$$(T_R^a)^m{}_l (T_R^a)^l{}_n = C_2(R)\, \delta^m{}_n$$

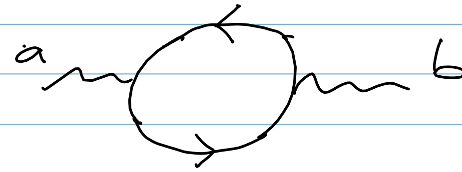
$$(T_R^a)^m{}_n (T_R^b)^n{}_m = T(R)\, \delta^{ab}$$

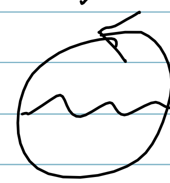
Bird Track Notation

$(T_R^a)^m{}_n =$



$C_2(R)\,\delta^m_n =$ 

$\delta^{ab}\,T(R) =$ 

 $=$ 

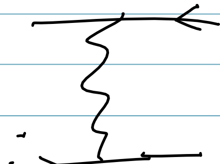
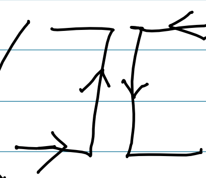
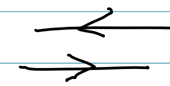
$$d(R)\,C_2(R) = d(Ad)\,T(R)$$

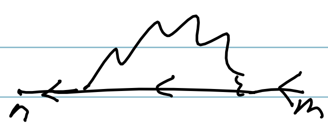
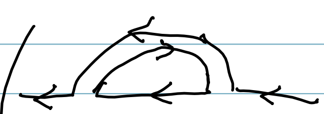
$$T(\square) = \tfrac{1}{2} \qquad T(Ad) = N$$

$$C_2(\square) = \frac{N^2-1}{2N} \qquad C_2(Ad) = N$$

for defining N dim. rep.

$$(T^a)^l_{\ p}\,(T^a)^m_{\ n} = \frac{1}{2}\left(\delta^l_n\,\delta^m_p - \frac{1}{N}\,\delta^l_p\,\delta^m_n\right)$$

 $= \frac{1}{2}\Big($  $- \frac{1}{N}$  $\Big)$

$C_2(\square)\,\delta^m_n =$  $= \frac{1}{2}\Big($  $- \frac{1}{N}$ 

$= \frac{1}{2}\left(N - \frac{1}{N}\right)$ $\overset{\longleftarrow}{_{n\qquad m}}$

$$= \frac{N^2-1}{2N}\,\delta^m_n$$

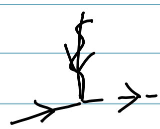
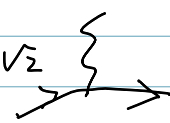
For the R charge to be a quantum symmetry the anomaly must vanish

$0 =$  $+$ 

$$0 = 1\cdot T(Ad) + (R-1)\,T(\square)\,2F$$

$$0 = N + (R-1)\,\tfrac{1}{2}\,2F$$

$$(R-1) = \frac{-N}{F} \quad \Rightarrow \quad R = \frac{F-N}{F}$$

 $= Y = \sqrt{2}\,g = \sqrt{2}$ 

$$\beta_g = \mu\frac{dg}{d\mu} = \frac{-g^3}{16\pi^2}\left(\frac{11}{3}T(Ad) - \frac{2}{3}T(F) - \frac{1}{3}T(S)\right)$$

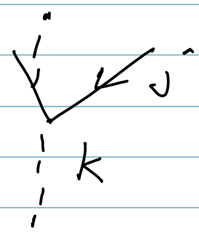
$$= \frac{-g^3}{16\pi^2}\left(\frac{11}{3}T(Ad) - \frac{2}{3}T(\square)2F - \frac{2}{3}T(Ad) - \frac{1}{3}T(\square)2F\right)$$

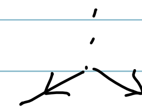
$$= \frac{-g^3}{16\pi^2}\left(\frac{9}{3}N - \frac{3}{3}F\right)$$

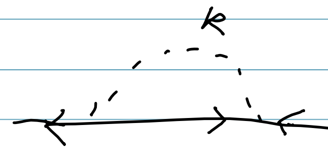
$$= \frac{-g^3}{16\pi^2}\left(3N - F\right)$$

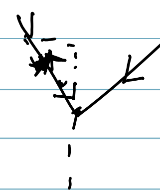
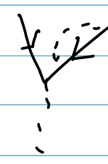
check $Y = \sqrt{2}\, g$ independent of μ
Machacek & Vaughn

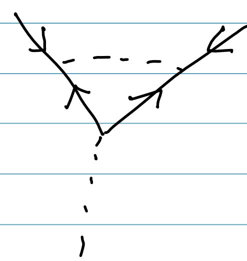
$$(4\pi)^2 \beta_Y = \frac{1}{2}\left(Y_2^\dagger(F)\, Y^k + Y^k\, Y_2(F)\right) + 2\, Y^p Y^{\dagger k} Y^p$$
$$+ Y^p \,\mathrm{Tr}\, Y^{\dagger p} Y^k - 3 g^2 \{ C_2(F), Y^k \}$$

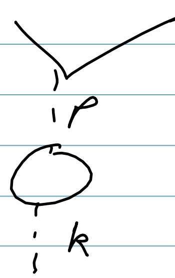
$Y^k_{ij} =$ 

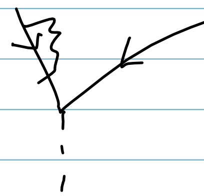
$Y^{k\dagger}$ 

$Y_2(F) = Y^{\dagger k} Y^k \sim$ 

$Y_2^\dagger(F)\, Y^k + Y^k Y_2(F) \sim$  

$Y^p Y^{\dagger k} Y^p \sim$ 

$Y^p \,\mathrm{Tr}\, Y^{\dagger p} Y^k \sim$ 

$\{ C_2(F), Y^k \} \sim$  $+$