PRESENTING: "SUPERCONFORMAL FLAVOR SIMPLIFIED" ; D. POLAND & D. SIMMONS-DUFFIN
arXiv: 0910.4585 (hep-ph)

[NOTICE: IN LIGHT OF ISSUES THIS SEMESTER WITH TALK LENGTHS, RESTLESSNESS, & ATTENTION SPAN, I AM PREPARING A SHORT TALK. [EVEN WITH DISCUSSION, I DON'T INTEND TO USE THE WHOLE 1.5 HOUR.] ... I ENCOURAGE OTHERS TO CONSIDER THIS AS WELL.]

WE WILL ONLY FOCUS ON GENERAL TOOLS & PRINCIPLES THAT CAN BE LEARNED FROM THIS PAPER! (§2, maybe §3.1)

↳ I THINK THIS IS WHAT IS APPROPRIATE FOR A JOURNAL CLUB TALK. "REALISTIC MODELS" ARE 'DETAILS' & TEND TO BE LESS INTERESTING FOR THOSE WHO ARE NOT ACTIVELY WORKING ON SIMILAR MODELS ALREADY.

I ENCOURAGE BROAD DISCUSSION, BUT I DO NOT HAVE MANY ANSWERS.

Refs.

★ 0910.4585 : THIS PAPER. WE ARE ONLY LOOKING @ P. 4-10 ... IF YOU'RE SITTING @ MY TALK AND ARE JUST LOOKING AT THE PAPER RIGHT NOW, OR PERHAPS YOU DIDN'T EVEN PRINT THE PAPER BUT JUST PRINTED MY NOTES... THEN I AM VERY DISAPPOINTED IN YOU. ῎ IT'S OK. WE CAN STILL BE FRIENDS.

- http://github.com/davidsd/lie

  ↳ THIS IS DAVID SD'S PYTHON CODE FOR WORKING W/ LIE GROUP REPRESENTATIONS, BASED ON LiE BY VAN LEEUWEN, COHEN, & LISSER ('90s).

  WE WILL NOT DISCUSS THIS, BUT IT IS A BROADLY APPLICABLE MODEL BUILDING TOOL THAT I THINK IS WORTH MENTIONING.

- hep-th/0304128 : THE ORIGINAL a-MAXIMIZATION PAPER, see also follow ups. RENORM EST ~ 2003.

  ↳ OTHER GOOD REFS INCLUDE WECHT'S CAMBRIDGE TALKS, TERNING'S BOOK.

- hep-th/0007240 : REVIEW OF SCFT AS OF 2000 (BEFORE a-MAXIMIZATION!)

- hep-ph/000625 : ORIGINAL "SUPERCONFORMAL FLAVOR" PAPER. (SEE ALSO REFS THEREIN FOR ORIGINAL ANARCHY REFS.)

  ↳ χral STRONG SECTORS. (PRESENT PAPER USES VECTOR)

MOTIVATION & INTRODUCTION

1. a-MAXIMIZATION

SOME OF YOU MAY REMEMBER OUR DISCUSSION OF a-MAXIMIZATION FROM WINTER CAMP. I WILL ASSUME THAT YOU DON'T SINCE PEOPLE SEEM TO QUICKLY FORGET ANYTHING I SAY.

a-MAXIMIZATION IS A SURPRISING & POWERFUL TOOL IN SUPERCONFORMAL FIELD THEORIES. {developed by Intriligator & Wecht as a grad student @ the time!}

FACT : "DISTINGUISHED $U(1)_R$" $\xleftrightarrow{\text{SUSY}}$ CONFORMAL GROUP $\cup$ scale transformations

or, in different words, SUSY relates the [DISTINGUISHED] R CURRENT ANOMALY to the TRACE OF THE ENERGY-MOMENTUM TENSOR.

THIS IS A WELL-KNOWN FACT (see, eg, Freund §19) & RECENTLY HAS COME UP IN PAPERS ABOUT THE SUPERCURRENT.

eg. THE INCONSISTENCY OF FI TERMS IN SUSY & SUGRA (Komargodski & Seiberg, Dienes & Thomas, Butter) RECALL DC'S JOURNAL CLUB TALK ON 2 NOV '09 [it's nice to cite previous JC talks, esp. when the topics overlap ...]

THE WELL-KNOWN RESULT IS THAT FOR A SCFT,

ie @ AN RG FIXED POINT

$$\boxed{\dim(\mathcal{O}) = \tfrac{3}{2}\, R(\mathcal{O})}$$

SCALING DIM

$\mathcal{O}$: xnal op

[DISTINGUISHED] R-CHARGE

THIS LOOKS GREAT, BUT THERE'S A PROBLEM: WHICH R SYM IS DISTINGUISHED? U(1)-SYMS CAN MIX & WE GENERICALLY GET U(1)'s COMING FROM FLAVOR SYMMETRIES.

EVEN FOR RELATIVELY SIMPLE MODELS, ONE CAN GET ALL SORTS OF U(1)s THAT MAKE IT TEDIOUS (POSSIBLY INTRACTABLE) TO FIND THE DISTINGUISHED $U(1)_R$ IN THE <u>SUPERCONFORMAL SUPERCURRENT</u>. (that term is not redundant)

see "NO FI TERM" LITERATURE ABOVE. ALSO:

- Clark & Love hep-th/9506145
- West, <u>INTRO TO SUSY + SUGRA</u>
- Weinberg Vol III
- ORIGINAL FERRARA & ZUMINO ('75) PAPER

FORTUNATELY, INTRILIGATOR & WECHT PROVIDE US WITH A TRICK:

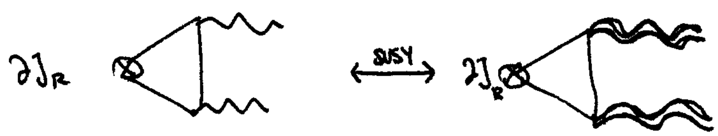
PARAMETERIZE A TRIAL (ie arbitrary) R-CHARGE AS

$$R_t = \underbrace{R_o}_{\text{actual SCFT R CHARGE WE WANT.}} + \sum_I \underbrace{s_I}_{\text{PARAMETERS}} F_I$$

F_I: GENERATOR OF U(1) SYMMETRY ASSOCIATED WITH THE I^{th} FLAVOR GROUP OF THE THEORY.

THEN R_o CAN BE PICKED OUT BY MINIMIZING $a(R_t)$ OVER s_I:

$$a(R_t) = \frac{3}{32}\left[3\,\mathrm{Tr}(R_t^3) - \mathrm{Tr}(R_t) \right] \qquad \text{(trace over fields)}$$



coef. of GAUGE ANOMALY coef of GRAV. ANOMALY

ie. $\min_{R_t} a(R_t) = a(R_o)$.

$\uparrow$ ie over $\{s^I\}$

[this is for FLIP's OWN NOTES. NOT FOR JC TALK.]

<u>DISCUSSION [skip this]</u> see: Wecht

$$\langle T_\mu{}^\mu \rangle = a\,(\text{Euler}) + c\,(\text{Weyl}) + \cdots$$

JUST WRITING W/RT GEOMETRIC QUANTITIES.

<u>CARDY's a-"thm"</u>: $a_{IR} < a_{UV}$

cf c-thm in 2D ; c is AN IMPORTANT OBJECT THAT COUNTS DOF.

IN A SCFT, CAN COMPUTE EXACT RESULTS FROM 't HOOFT ANOMALIES (AFGJ '97)

$$a = \frac{3}{32}\left(3\,\mathrm{Tr}\,R^3 - \mathrm{Tr}\,R\right)$$
$$c = \frac{1}{32}\left(9\,\mathrm{Tr}\,R^3 - 5\,\mathrm{Tr}\,R\right)$$

this comes from $\delta T = a(\delta\text{Euler}) + c(\delta\text{Weyl})$

CONTAINS ∂R, $T^\mu{}_\mu$

BOTH CONTAIN $[\text{Riem}][\widetilde{\text{Riem}}]$, $F_R \widetilde{F_R}$

get: $\partial R = (\underbrace{\#a + \#'c}_{\mathrm{Tr}\,U(1)_R})\,\text{Riem}\,\widetilde{\text{Riem}} + (\underbrace{\#''a + \#'''c}_{\mathrm{Tr}\,U(1)_R^3})\,F_R \widetilde{F}_R$

SO CAN INVERT LIN COMB. TO WRITE a & c.

~~[illegible]~~

<u>Some QUICK EXAMPLES</u> (following Wright)

1. <u>SQCD</u> : $SU(N_c)$ w/ N_f VECTORLIKE FLAVORS $Q, \tilde{Q}$

$$\text{ANOMALY} = \sum_i q_i T(r_i) = \underset{\substack{\uparrow \\ \text{GAUGINOS} \\ \text{IN Adj}}}{2N_c} + 2N_f\,(\underbrace{R[Q]-1}_{})$$

FERMION'S R CHARGE
note $R(Q) = R(\tilde{Q})$ so WE JUST DOUBLED THIS.

ANOMALY FREE $\Rightarrow$ $R[Q] = R[\tilde{Q}] = 1 - N_c/N_f$. ✓

NO NEED TO a-MAXIMIZE.

Very simple deformation.

2. <u>SQCD DEFORMED W/ ADJOINT MATTER, X</u> $(W_{\text{tree}} = 0)$

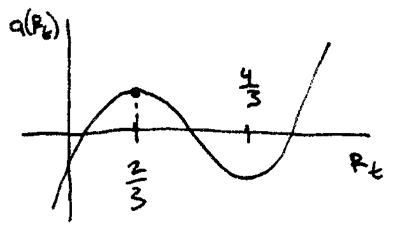
$$\text{ANOMALY} = \underbrace{2N_c + 2N_f\,(R[Q]-1)}_{\text{SQCD}} + \underbrace{2N_c}_{\text{ADJOINT}}\,(\underbrace{R[X]-1}_{\psi_X \text{ R CHARGE}})$$

ANOMALY FREE CONDITION NOW HAS 1 PARAMETER FAMILY!
ONE EQN, 2 UNKNOWNS $R[Q]$, $R[X]$.

[we won't use a max on this. instead, let's do a simpler example]

3. <u>FREE χSF Φ</u>

$$a(R_t) = 3(R_t - 1)^3 - (R_t - 1)$$



$$a(R_t)\big|_{\max} = a(R_0) \Rightarrow \boxed{R_0 = 2/3}$$ ✓

ONE WOULD HAVE TO DO THIS FOR THE R CHARGE OF EACH FIELD IN THE THEORY. THIS IS USUALLY DONE NUMERICALLY.

DISCUSSION [SKIP THIS - FOR FLIP'S NOTES ONLY]

Motivation of proof

$$\max\ a \Leftrightarrow \begin{cases} 1.\ \text{EXTREMUM}: & 9\,\mathrm{Tr}\, R_0^2 F_I = \mathrm{Tr}\, F_I \qquad \partial a/\partial s_I = 0 \\ 2.\ \text{MAXIMUM}: & \mathrm{Tr}\, R_0 F_I F_J < 0 \qquad \partial^2 a/\partial s_I \partial s_J < 0 \end{cases}$$

sanity check: free theory has $R_0 = 2/3$.

1.

$\Leftrightarrow$ EXTREMUM

2. CONFORMAL INVARIANCE : $\langle R F_I F_J \rangle \sim \langle F_I F_J \rangle$ (non-trivial)

POSITIVE DEF BY UNITARITY
OR, HOLOGRAPHICALLY TURNS INTO GAUGE CURRENTS IN BULK SO THAT THIS IS KIN. TERM W/ DEF SIGN.

IF FREE THY: $\langle R F_I F_J \rangle = -\frac{1}{3} \langle F_I F_J \rangle$

ie b/c $\langle F_I F_J \rangle > 0 \Rightarrow \langle R F_I F_J \rangle < 0$. $\Leftrightarrow$ MAXIMUM.

IR ACCIDENTAL SYMMETRIES COMPLICATE THINGS "Δ"

... there are some subtleties. (see, eg § 2.3) we won't discuss further.

ok, GOOD. SO NOW WE'VE MET a-MAXIMIZATION & WE KNOW WHAT IT'S GOOD FOR (giving R_0). BUT WHAT IS IT REALLY GOOD FOR?
ie: SO WHAT ?

Some past applications

- PROGRESS TOWARD 4D ZAMOLODCHIKOV c-THM
- INDIRECT PROOF (CHECK) OF SEIBERG DUALITY
- PROGRESS TOWARD PROOF OF AdS/CFT
- BRANE TILINGS IN STRING THY

⋮

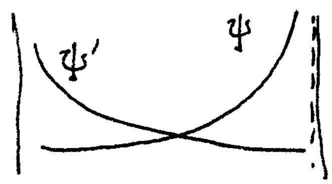
GEN IDEA: PROBE NONPERTURBATIVE REGION @ (near) SUPERCONF. FIXED PT.

→ pheno/model-building games we can play w/ strong coupling.

"MOTIVATION & INTRO" PT II ⟵ most of this talk is motivation & intro

OUR GROUP HAS A LOT OF EXPERIENCE W/ STRONG COUPLING : RS
IN FACT, ONE TOPIC THAT WE'VE EXPLORED RECENTLY ARE
ANARCHIC FLAVOR MODELS. (DC, YT, FT)

→ IDEA: FLAVOR HIERARCHIES IN YUKAWA SECTOR : wtf?
NATURALNESS ⇒ $\mathcal{O}(1)$ DIM'LESS PARAM.
↓
RS PROVIDES A WAY TO TURN SMALL #'S INTO BIG #'S BY WARPING.
ORIGINALLY USE WARPING FOR HIERARCHY PROBLEM (HIGGS),
BUT NOW PIGGY BACK FLAVOR HIERARCHY AS "ADDED BONUS"



MAKE 4D YUKAWAS EXPONENTIALLY SMALL BY HAVING A SMALL 5D WAVEFUNCTION OVERLAP W/ ANARCHIC $\mathcal{O}(1)$ YUKAWA COUPLINGS.

THIS WAVEFUNCTION LOCALIZATION IS CONTROLLED BY THE BULK MASS PARAMETER, $c \equiv RM \sim \mathcal{O}(1)$. SMALL ~~[illegible]~~ DIFFERENCES IN c GIVE BIG HIERARCHIES.

⇒ these parameters are inputs to the model.
NATURAL, BUT AN ADDITIONAL SOURCE OF DOFS. :(

this whole picture is dual to a strongly coupled theory VIA THE ADS/CFT CORRESPONDENCE. outputs of a thy.

IN THE PICTURE, THE c PARAMETERS CORRESPOND TO ANOMALOUS DIMENSIONS
↓
MOTIVATES A DIFFERENT PERSPECTIVE: START FROM THE CFT SIDE AND CONSIDER A STRONGLY COUPLED THY THAT PREDICTS THE APPROPRIATE ANOMALOUS DIMENSIONS.

... OF COURSE STRONGLY-COUPLED THEORIES ARE HARD TO CALCULATE IN, SO WE SHOULD GO TO A REGIME WHERE WE HAVE SOME TRICKS; SUPERCONFORMAL THEORY.

IDEA: WE STILL HAVE ANARCHY: YUKAWAS & ANOMALOUS DIM ARE $\mathcal{O}(1)$
BUT RG FLOW GENERATES FLAVOR HIERARCHIES.

ORIGINALLY PROPOSED BY NELSON & STRASSLER (hep-ph/0006251)
BUT DETERMINING ANOMALOUS DIM IN SCFT ⟷ DETERMINE R CHARGES.
→ SO DP & DSD USED a-MAXIMIZATION TO WORK OUT PREVIOUSLY "INCALCULABLE" MODELS.

SINCE WE'LL BE INTRODUCING AN ADDITIONAL (STRONGLY COUPLED) SECTOR, THESE MODELS TEND TO INTRODUCE LOTS OF NEW FIELDS.

→ WANT "FLAVOR PHYSICS" @ HIGH SCALE (eg near M_{Pl}) SINCE

LANDAU POLE → 1. WORRY ABOUT PERTURBATIVITY OF SM GAUGE COUPLINGS
2. WORRY ABOUT BARYON # & LEPTON # OPERATORS } "SUSY FLAVOR PROBLEM"

⇓

ASSUME CONFORMAL 'FLAVOR' SECTOR LIVES ABOVE M_{GUT}

in fact, these kinds of models shed new light on subtleties in the SUSY FLAVOR PROBLEM.

↓

SO DP & DSD LOOK @ VECTORLIKE $SU(5)_{GUT}$ REPS.
WE WON'T GO INTO THEIR 'REALISTIC MODELS'

↳ BUT RECALL TYPICAL SM EMBEDDING INTO SU(5)

$$\bar{F}_i = \begin{pmatrix} e \\ -\nu \\ \hline \bar{d}_1 \\ \bar{d}_2 \\ \bar{d}_3 \end{pmatrix} \begin{matrix} \} L \\ \\ \} d_R \end{matrix} \qquad T_i = \left(\begin{array}{cc|ccc} 0 & \bar{e}_R & u_1 & u_2 & u_3 \\ & 0 & d_1 & d_2 & d_3 \\ \hline & & 0 & \bar{u}_3 & -\bar{u}_2 \\ & & & 0 & \bar{u}_1 \\ & & & & 0 \end{array}\right) \} Q$$

$\bar{5}$ ↑ ALSO $H \in 5$, $\bar{H} \in \bar{5}$

10 ↑ DP & DSD CONSIDER "10-CENTERED MODELS" WHERE SUPPRESSION IS ATTACHED TO T_i s.

DP & DSD DISCUSS PATTERNS IN THE CKM & MNS MATRICES THAT SHOW THAT WAVEFUNCTION RENORMALIZATION OF F, T, H COULD PLAUSIBLY GENERATE THE SM FLAVOR STRUCTURE; § 2.1.

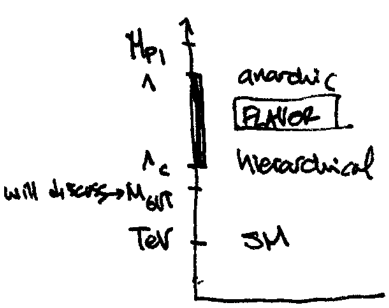
Lightning review → RG? BUT YUKAWA ⊂ W & W IS NOT RENORMALIZED! HOWEVER, THE KÄHLER POT IS RENORMALIZED; DYNAMICAL ORIGIN OF FLAVOR HIERARCHY.

$$\mathcal{L} = \int d^4\theta \sum_i Z_i \Phi_i^\dagger \Phi_i$$

s.t. CANONICAL NORMALIZATION GIVES SUPPRESSION $\epsilon_i = Z_i^{-1/2}$ FOR EA FIELD IN AN OPERATOR

$$\frac{d \log Z_i}{d \log \mu} = -\gamma_i \quad \Rightarrow \quad \epsilon_{\Phi_i} = e^{-\frac{1}{2}\int_{\log \Lambda_c}^{\log \Lambda} \gamma_i \, d\log \mu}$$

Λ : UV scale @ which YUKAWAS ANARCHIC
Λ_c : FLAVOR SECTOR DECOUPLES



} WANT O(1) γs, SO LARGE RG EVOL FROM $\Lambda \to \Lambda_c$

APPROXIMATE γ VIA: IGNORE g_{SM}, YUKAWAS & TREAT THEM AS SOFT W/ STRONG GAUGE GROUP G.
⇒ γ CONST,
$$\epsilon_{\Phi_i} = \left(\frac{\Lambda_c}{\Lambda}\right)^{\frac{1}{2}\gamma_i}$$

FACT: IN THE "PHYSICAL BASIS" WHERE FIELDS ARE CANONICALLY NORMALIZED @ ea μ, FOR $W = \cdots + c\,\mathcal{O} + \cdots$

$$\frac{\partial c}{\partial \log\mu} \equiv \beta_c = c(\dim\mathcal{O} - 3)$$

SM FIELDS, NOT CHARGED UNDER STRONGLY COUPLED FLAVOR SECTOR, G.

for a YUKAWA COUPLING $W = y\,FTH$ or $y\,TTH$

$$\frac{\partial y}{\partial \log\mu} = y\left(3 + \Sigma\frac{\gamma_i}{2} - 3\right) = \frac{y}{2}\left(\gamma_{F/T} + \gamma_T + \gamma_H\right)$$

$$\Rightarrow\ y^{ij}_{u,d}(\Lambda_c) = \left(\frac{\Lambda_c}{\Lambda}\right)^{\frac{1}{2}\Sigma\gamma} y^{ij}_{u,d}(\Lambda)$$

(this is the flavor structure that is frozen in

~~TOY MODEL MOTIVATION~~

$\boxed{\text{OUR GOAL}}$

DONE BY NELSON + STRASSLER, BUT THEIR CALCULABLE MODELS NEEDED MANY FIELDS & INTERACTIONS ... we'll use a-MAX

ANARCHY IN UV YUKAWAS
O(1) ANOMALOUS DIM ← INPUT "STRUCTURE" IN RS MODELS IS NOW AN OUTPUT

BUT: LET GROUP REPRESENTATIONS GIVE US THE STRUCTURE THAT EXPONENTIATES INTO FLAVOR HIERARCHIES.

TOY MODEL (§ 2.2.1)

	$SU(5)_{GUT}$	$G = SU(N)$
$X + S$	$10 + 1$	$\square$
$\bar{X} + \bar{S}$	$\overline{10} + 1$	$\bar{\square}$

m CFT regime

CFT sees SUSY QCD w/ 11 FLAVORS; CFT FIXED POINT @ $\frac{3}{2}N < 11 < 3N$

$\Delta W = h(\mu)\,\mu^{3-d}\,\mathcal{O}$
DEFORMATION

$\dim[\mathcal{O}] = d$ ("ENGINEERING" DIMENSION)
relevant OPERATOR → GROWS IN IR

AS $\mu \to$ IR, THIS OP. GROWS UNTIL $\beta_h \approx 0$ @ NEW FIXED POINT

$$\beta_h = (\dim\mathcal{O} - 3)h = (d + \gamma_{\mathcal{O}}/2 - 3)h$$

$\dim\mathcal{O} \approx 3$, OP BECOMES MARGINAL, $h(\mu) \approx h_*$

SO WE'VE STARTED @ UV SCALE Λ, DEFINED Λ_c AS $h(\Lambda_c) = h_*$.

WHAT $\mathcal{O}$'s ARE PERMITTED?

THE TOY MODEL ADMITS ONLY ONE RELEVANT GAUGE INVT COUPLING TO MSSM.

irrelevant ones die over $\Lambda \to \Lambda_c$ running

we "WEAKLY GAUGE" MSSM GROUP.

$$\boxed{W_{int} = h\,[T_1 \bar{X}]\,S}$$

SINGLET

SU(5) INDICES CONTRACTED

SU(3)$_F$ INDICES CONTRACTED

MSSM SU(5)$_{GUT}$ TENSOR FIELD

SU(5)$_{GUT}$ TENSOR OF STRONG SECTOR

THE "1" IN T_1 ~~OF~~ INDEXES A FLAVOR COMBINATION. WE WILL MAKE THIS GENERATION LIGHT.

IN THIS TOY MODEL WE TREAT h AS AN SU(3)$_F$ SPURION THAT PICKS OUT A T_i.

defines

GOOD. NOW WE JUST HAVE TO DETERMINE γ's OF SM FIELDS (γ_{T_i})

$$a(\vec{R}_t) = \frac{3}{32}\left[\, 2(N^2-1) + \sum_i \dim(r_i)\left(3(R_i-1)^3 - (R_i-1)\right)\right]$$

$(R_X, R_{\bar{X}}, R_S, R_{\bar{S}}, R_{T_1})$

T_2 & T_3 ARE CFT SINGLETS
$\Rightarrow R = (2/3)$, ie free

ADDITIONAL CONSTRAINTS

1. ANOMALY FREE W/rt $G = SU(N) \Rightarrow 0 = T(G) + \sum_i (R_i - 1)\,T(r_i)$

   $\hookrightarrow$ remark: this just gives $\beta^{NSVZ}_{g_G} = 0$; ie they = CONFORMAL.

2. $T_1 \bar{X} S$ MUST BE MARGINAL W/rt G

   $\hookrightarrow$ dim in W $= 3$; ~~[illegible]~~

   BUT @ SCFT FIXED POINT, $D = \frac{3}{2}R$

   $\Rightarrow \sum R = 2 = R_{T_1} + R_{\bar{X}} + R_S$

DOING THIS ~~[illegible]~~ a-MAXIMIZATION, WE OBTAIN TABLE 2. THE RELEVANT RESULT

	N=4	N=5	N=6	N=7
R_{T_1}	.69	.77	.92	1.19

SCFT FOR $\frac{3}{2}N < N_F < 3N$ ($N_F = 4$)

~~typically~~ ...

AS N BIGGER, MORE STRONGLY COUPLED, LARGER R_{T_1}.

$\epsilon_{T_1} = \left(\frac{\Lambda_c}{\Lambda}\right)^{\frac{3}{2}R_{T_1} - 1} \Rightarrow$ LARGER R_{T_1} $\to$ SMALLER CONFORMAL WINDOW.

THAT'S IT. I WANT TO CLOSE (if there's time) WITH SOME REMARKS ABOUT DP & DSD'S VECTORLIKE MODELS

- NELSON & STRASSLER: XTAL MODELS : Λ_c GEN DYNAMICALLY BY EXTRA GAUGE GRP.
- DP+PSD: VECTORLIKE MODELS → SIMPLER

↓

SIMPLIFIES CFT EXIT : JUST ~~AS~~ INTRODUCE A MASS TERM.

eg. $W \supset m_X X\bar{X} \rightarrow \Lambda_c = m_X \left(\frac{\Lambda_c}{\Lambda}\right)^{\frac{1}{2}(\gamma_X+\gamma_{\bar{X}})}$

- SIMPLEST MODIFIC OF TOY MODEL: "10 - CENTERED" MODEL WHERE T_1 & T_2 GET LARGE γ

$$W_{int} = \underset{\substack{\uparrow \\ XQ}}{T_1\,\mathcal{O}_1} + \underset{\substack{\uparrow \\ \bar{X}S}}{T_2\,\mathcal{O}_2}$$

	$SU(5)_{GUT}$	$G=SU(N)$
$X+\bar{Q}+S$	$10+\bar{5}+1$	$\square$
$\bar{X}+Q+\bar{S}$	$\bar{10}+5+1$	$\bar{\square}$

exhausts ops. (marginal, MSSM coupling, gauge inv.)

- IN SIMPLEST MODELS, $\mathcal{O}_1$ & $\mathcal{O}_2$ VIOLATE LEPTON + BARYON #

SO @ Λ_c, INTEGRATING OUT CFT SECTOR → p^+ DECAY OPS. (dim 6)

↳ SUPPRESSION IS $4\pi^2/N\Lambda_c^2$

⇒ REQ. ~~A~~ $M_{GUT} \lesssim \Lambda_c < \Lambda \lesssim M_{Pl}$ ⇒ <u>SMALL</u> CONF WINDOW

⇒ FAIRLY STRONGLY COUPLED

TURNS OUT THAT LANDAU POLE IS TOO STRONG IN "SIMPLEST-EST" MODELS
LARGEST ALLOWED N'S IN CONFORMAL RANGE STILL GIVE LANDAU POLES.

SUMMARY

1. a-MAXIMIZATION : determine CANONICAL $U(1)_R$ OF SCFT
2. CAN USE STRONG DYNAMICS TO GEN FLAVOR HIERARCHIES
   - γ'S ARE AN OUTPUT, NOT AN INPUT
3. TENSION : eg. LANDAU POLE VS. p^+ DECAY.