Aspects of (0,2) theories

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A progress report on d=2 QFT with (0,2) supersymmetry

⋆ Gross, Harvey, Martinec & Rohm, *Heterotic string theory (I)*
NPB**256**, received Feb. 26 1985

There are many paths to (0,2) theories

- ⋆ critical heterotic strings with $\mathbb{R}^{1,3}$ N=1 superPoincaré
- ⋆ heterotic stringy geometry for $\mathcal{E} \to X$
- ⋆ surface defects/strings in d=4 N=1 gauge theory
- ⋆ AdS_3/CFT_2 and (2,0) compactification
- ⋆ last refuge of holomorphy in SUSY QFT

Plan

1. general properties
2. heterotic geometries
3. linear sigma models
4. accidents
5. outlook

(0,2) supercurrents live in an $\mathcal{S}$-multiplet

[Dumitrescu&Seiberg,**1106.0031**]

- $\mathbb{R}^{1,1}$: $x^\mu = (x^0, x^1)$ or light-cone $x^{\pm\pm}$
- S^μ_+, $\overline{S}^\mu_+$ conserved supercurrents $\rightarrow Q_+$, $\overline{Q}_+$
- energy-momentum tensor $T^{\mu\nu} \rightarrow P^\mu$

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- weak assumptions $\implies T, S, \overline{S} \subset \mathcal{S}$-supermultiplet

$$\{Q_+, \overline{S}_{+\pm\pm}\} = -T_{\pm\pm++} \pm i\partial_{\pm\pm} j_{++} \qquad \{Q_+, S_{+++}\} = 0$$
$$\{Q_+, S_{+--}\} = i\overline{C}\ .$$

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- spin 1 operator j_{++} not necessarily conserved
- $\overline{C} \neq 0 \implies$ deformed (0,2) supercurrent algebra, a UV property

Many (0,2) QFTs have $\mathcal{R}$-multiplet

[Dumitrescu&Seiberg,**1106.0031**]

- $\overline{C} = 0$
- conserved R-current $j^\mu \leftrightarrow j_{\pm\pm} \to$ conserved charge R
- $j^\mu, S^\mu_+, \overline{S}^\mu_+, T \subset \mathcal{R}$-multiplet $\implies$ standard (0,2) SUSY algebra

$$\{Q_+, \overline{Q}_+\} = -4P_{++} \qquad [R, Q_+] = -Q_+ \qquad [R, \overline{Q}_+] = +\overline{Q}_+$$
$$\{Q_+, Q_+\} = 0 \qquad \{\overline{Q}_+, \overline{Q}_+\} = 0$$

- a key property: $\overline{Q}_+^2 = 0$
- $\overline{C}$ can be generated by quantum corrections, e.g. $(0,2)$ $\mathbb{P}^1$ NLSM

(0,2) SCFTs are the building blocks for (0,2) QFTs

⋆ $T^\mu_\mu = 0$ on Euclidean world-sheet

$$\text{Vir}_{c} \oplus \overline{\text{N=2 sVir}}_{\,\overline{c}} \qquad T(z) \qquad ; \qquad \overline{J}(\overline{z})\ ,\ G^{\pm}(\overline{z})\ ,\ \overline{T}(\overline{z})$$

$$h \qquad\qquad \overline{q} \qquad\qquad \overline{h}$$

⋆ we will discuss unitary and compact SCFTs

⋆ characterization

- symmetries, e.g. left-moving Kac-Moody algebra $\supset \text{U}(1)_{\text{L}}$ current J
- elliptic genus $Z = \text{Tr}_{RR}(-1)^F q^H \overline{q}^{\overline{H}} y^{J_0}$
- spectrum of marginal operators [depends on moduli!]
- 2 and 3-point functions [super-primary not sufficient!]

Marginal (0,2) deformations are characterized

- SUSY marginal deformations via conformal perturbation theory [Bertolini et al, **1405.4266**], cf N=1 d=4 [Green et al, **1005.3546**]

$$\Delta S = \lambda \int d^2 z \{Q_+, U\} + \text{h.c.}$$

U a chiral primary operator $\quad h = 1, \ \ \overline{h} = \overline{q}/2 = 1/2$

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- obstructions:
  - "D-term" $(\mathcal{J}_{\text{KM}}(z), U, \overline{U}) \to$ long multiplet $\implies \lambda$ breaks KM
  - "F-term" $(U_{\overline{q}=1}, F_{\overline{q}=2}) \to$ long multiplet
- some consequences:
  - Kähler moduli space
  - no F-term obstructions for $\overline{c} < 6$

RG flows satisfy some simple constraints

- ⋆ relevant $\Delta S = \lambda \int d^2z\{Q_+, U\} + \text{h.c.}$; U c.p. with $\overline{q} < 1$
- ⋆ $(c - \overline{c})$ is RG-invariant; $\dot{c} < 0$
- ⋆ $\overline{c}_{\text{IR}}$ via c-extremization [Benini&Bobev,**1211.4030**,**1302.4251**]
- ⋆ elliptic genus is RG-invariant
- ⋆ holomorphic 1/2-twisted chiral ring of $\overline{Q}_+$-closed operators

  [Witten,**0504078**],[Tan&Yagi,**08014742**],[Borisov&Kaufmann,**1102.5444**]
- ⋆ topological heterotic rings generalize A and B model of (2,2)

  [Adams,Basu&Sethi,**0309226**],[Adams,Distler&Ernebjerg,**0506263**]
- ⋆ but watch out for accidents!

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(0,2) NLSMs yield a geometric realization

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★ conformal invariance for $\dim_{\mathbb{C}} X = 3 \implies$

[Strominger;Hull;Sen,**'86**],[Groot Nibbelink&Horstmeyer,**1203.6827**]

- K_X holomorphically trivial and $\mathcal{E}$ stable
- (X, ω, Ω) define SU(3) structure + conformal balance
- $dH = \frac{\alpha'}{4}\left[\mathrm{tr}\,\mathcal{R}^2 - \mathrm{tr}\,\mathcal{F}^2\right]$

The standard embedding is a heterotic geometry

⋆ (X, ω, Ω) is CY 3-fold; $\mathcal{E} = T_X$; $H = 0 \implies$

- (2,2) SCFT $\quad c = \overline{c} = 9 \quad \overline{q} \in \mathbb{Z}$
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- ⋆ $H^1(T_X^*) \leftrightarrow \mathbf{27} \qquad H^1(T_X) \leftrightarrow \overline{\mathbf{27}}$
- ⋆ $W \supset \partial_{ijk}\mathcal{F}(t)\mathbf{27}^i \cdot \mathbf{27}^j \cdot \mathbf{27}^k \leftrightarrow$ special geometry [Dixon et al, **NPB'90**]

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- ⋆ W encodes obstructions to $H^1(\text{End } T_X)$
  - classical via alg-geom
  - quantum via world-sheet instantons

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  sugra [Anderson et al,**1107.5076**] world-sheet [IVM&Sharpe,**1110.1886**]

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- world-sheet instantons can ruin conformal invariance

  zoo or bestiary?

Torsional geometries are more mysterious

- ⋆ X topologically non-Kähler e.g. odd b_1
- ⋆ string-scale cycles $\implies$ α' expansion formal
- ⋆ known examples: $\mathrm{X} = T^2$ principal bundle over K3

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- ⋆ torsional geometries with N=2 spacetime supersymmetry

  [IVM,Minasian&Theisen,**1206.1417**]
  - classified
  - exhibit (0,2+4) worldsheet susy — cf [Banks&Dixon,**NPB'88**]
  - conjecture: IIA duals are K3-fibered but not elliptically fibered

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Linear sigma models offer key insights

- ⋆ two-dimensional gauge theories with (0,2) susy [Witten, **9301042**]
- ⋆ simple UV physics
  - chiral bosonic multiplets Φ and fermi multiplets $\Gamma^A = \gamma_-^A + \cdots$
  - gauge group G and holomorphic potentials $E^A(\Phi)$, $J_A(\Phi)$, $J \cdot E = 0$
  - "phases" determined by Fayet-Iliopoulos parameters
  - geometric phases include $X \subset V_{\text{toric}}$ & $\mathcal{E} \to X$ monad bundle

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- ⋆ rich IR physics
  - vast classes of (2,2) and (0,2) SCFTs
  - interpolate between disparate descriptions — CY/LG correspondence
- ⋆ the art of the linear sigma model : lift IR queries to UV fields

Developments in (0,2) linear sigma model technology

- ⋆ elliptic genus [Gadde&Gukov,**1305.0266**],[Benini et al,**1308.4896**]

  $\Longrightarrow$ probe novel (0,2) SCFTs, e.g. [Gadde et al,**1404.5314**],[Haghighat et al,**1412.3152**]

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- $\star$ $\{$holomorphic parameters$\}/\{$redefinitions$\}$ for deformations of (2,2) [Kreuzer et al,**1001.2104**]

  $\Longrightarrow$ (0,2) mirror map for pairs $(X, \mathcal{E})$, $(X^\circ, \mathcal{E}^\circ)$ [IVM&Plesser,**1003.1303**]

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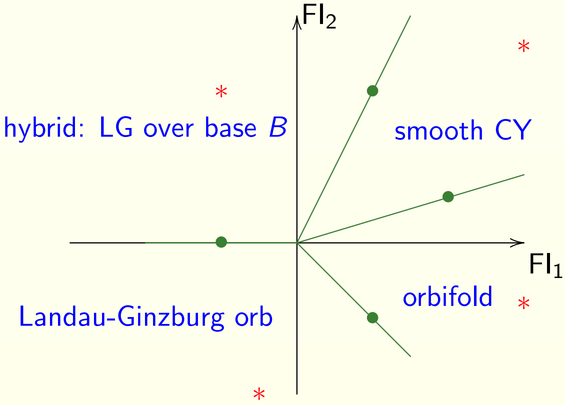
- ⋆ torsional linear sigma models[Adams et al,**0611084**,**1206.5815**],[Quigley et al,**1206.3228**,**1212.1212**]

(0,2) marginal deformations via (2,2) linear sigma model

- ⋆ marginal deformations depend on the phase

  [Kachru&Witten,**9307038**],[Distler&Kachru,**9309110**],[Aspinwall et al,**1008.2156**],[Bertolini et al,**1307.7064**]



- ⋆ a rich laboratory for explorations, e.g. (0,2) McKay [Aspinwall&Gaines,**1404.7802**]

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Life without accidents would be nice

- ⋆ (0,2) Landau-Ginzburg theory with $\mathrm{U}(1)_{\mathrm{L}} \times \mathrm{U}(1)_{\mathrm{R}}$ symmetry

$$L = \text{free kinetic term} + \int d\theta \sum_A \Gamma^A J_A(\Phi; \alpha) + \text{h.c.}$$

- ⋆ quasi-homogeneity: $J_A(t^q \Phi; \alpha) = t^{-Q_A} J_A(\Phi; \alpha)$
- ⋆ charges (q, Q) determine family of LG theories
- ⋆ generic $J_A \implies \mathrm{U}(1)_{\mathrm{L}} \times \mathrm{U}(1)_{\mathrm{R}}$ symmetry
- ⋆ IR SCFT with $(c, \overline{c})$ & elliptic genus determined by (q, Q)

There are accidents in (0,2) RG flows

[Bertolini et al,**1405.4266**]

- ⋆ LG kinetic term irrelevant and slaved to superpotential
- ⋆ $J_A(\Phi; \alpha)$ and $J_A(\Phi; \alpha')$ are IR-equivalent if linked by field redefinition
- ⋆ symmetries of $J_A(\Phi; \alpha)$ depend on α

  $\Longrightarrow$ c-extremization can lead to $c(\alpha) \neq c(\alpha')$!

  $\Longrightarrow$ UV parameter space stratified according to basin of attraction

  $\Longrightarrow$ naive c may not have realization for any α
- ⋆ how can we ensure that accidents do not occur?

Outlook

- ⋆ impressive results for just two supercharges
- ⋆ many challenges
- ⋆ some key directions
  - when does a (0,2) linear sigma model yield a heterotic CFT?
  - what is (0,2) mirror symmetry beyond deformations of (2,2)?
  - when is a (0,2) RG-flow accident-free?
  - which torsional geometries yield heterotic CFTs?
  - what sorts of geometric transitions occur in (0,2)?
  - are there nice local models?
  - is there a class of (0,2) "minimal models"?
- ⋆ hope: new sources of (0,2) questions may also yield new (0,2) answers
- ⋆ a little (0,2) book is in the works!