Title: New attractors in SU(3)xSU(3) structure compactifications

Date: Jun 05, 2008 02:45 PM

URL: http://pirsa.org/07060084

Abstract: It was proposed recently that type IIB orientifold compactifications on CY(3) in the presence of fluxes exhibit an attractor mechanism similar to the one in black hole physics, in other words that minimizing the relevant scalar potential is equivalent to solving a system of attractor equations. So far this conjecture has been verified only numerically. We show by analytical means that the conjectured susy attractor equations do indeed give supersymmetric minima of the relevant scalar potential. Furthermore, we obtain attractor equations for the most general N=1 flux compactifications of type IIA/B string theory, namely compactifications on SU(3)xSU(3) structure spaces.

Motivation

– Attractor mechanism:

In 4d $\mathcal{N} = 2$ SUGRA + vector multiplets:

$\exists$ susy BH solutions with electric and magnetic charges

$\longrightarrow$ various scalar fields (moduli)

At BH horizon:

algebraic equations: moduli $\longleftrightarrow$ charges

Black hole potential: $V_{BH}(\text{scalars}) = |DZ|^2 + |Z|^2$

$\longrightarrow$ susy critical points of V_{BH} $\Leftrightarrow$ attractor equations

– String compactifications:

6 internal dimensions: $\exists$ many deformations with no energy cost

In 4d effective theory:

Deformation parameters $\longrightarrow$ massless fields without a potential (moduli)

BUT: Moduli vevs determine many 4d properties ...

$\Rightarrow$ huge vacuum degeneracy,
lack of predictability of 4d coupling constants

$\longrightarrow$ Need to stabilize the moduli !

– IIB CY(3) orientifolds:

CY(3): complex structure moduli and Kähler structure moduli

Background fluxes $\Rightarrow$ potential for complex structure moduli

$N = 1$ SUGRA in 4d:

$$V = |DZ|^2 - 3|Z|^2 \,. \qquad Z = e^{\frac{K}{2}} W$$

Supersymmetric minima: $DZ = 0$

Proposal: special Kähler geom. $\Rightarrow$ $DZ = 0 \leftarrow$ attractor eqs

$\longrightarrow$ New perspective on moduli stabilization!

Generic feature or accident?

Contents

- Motivation
- Black hole attractors
- Flux vacua attractors
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- Generalizations
  - Heterotic on non-Kähler manifolds
  - Type II on $SU(3) \times SU(3)$ structure
- Summary

Black hole attractors

– $N = 2$, $d = 4$ SUGRA:

$N = 2$ supergravity coupled to n $N = 2$ vector multiplets

All couplings – determined by a single function, prepotential

- Special Kähler geometry: $\{t^i, \bar{t}^{\bar{i}}\}$, $i = 1, \ldots, n$

symplectic sections: $(L^\Lambda(t), M_\Lambda(t))$, $\Lambda = 0, 1, \ldots, n$

$$i(\bar{L}^\Lambda M_\Lambda - L^\Lambda \bar{M}_\Lambda) = 1, \qquad D_{\bar{i}} L^\Lambda = (\partial_{\bar{i}} - \frac{1}{2} K_{\bar{i}}) L^\Lambda = 0$$

$$X^\Lambda = e^{-K/2} L^\Lambda, \; G_\Lambda = e^{-K/2} M_\Lambda: \quad \partial_{\bar{i}} X^\Lambda = 0, \; \partial_{\bar{i}} G_\Lambda = 0$$

$$K = -\ln i \left(\bar{X}^\Lambda G_\Lambda - X^\Lambda \bar{G}_\Lambda\right)$$

– BH attractor equations:

Extremal black holes: BPS states with charges $\{q_\Lambda, p^\Lambda\}$

$$q_\Lambda = \frac{1}{2\pi}\int_{S^2} \mathrm{Re}(\star F)_\Lambda\,, \qquad p^\Lambda = \frac{1}{2\pi}\int_{S^2} \mathrm{Re}F^\Lambda$$

Black hole potential: $V_{BH} = |Z|^2 + |DZ|^2\,,$

$$Z(t,\bar{t},q,p) = q_\Lambda L^\Lambda - p^\Lambda M_\Lambda \qquad \text{(central charge)}$$

Susy critical points: $D_i Z = \left(\partial_i + \frac{1}{2}K_i\right) Z = 0$

$$D_i Z = 0 \quad \Rightarrow \quad p^\Lambda = i(\bar{Z}L^\Lambda - Z\bar{L}^\Lambda)\,,\ \ q_\Lambda = i(\bar{Z}M_\Lambda - Z\bar{M}_\Lambda)$$

$$\{t^i, \bar{t}^{\bar{i}}\}|_{\text{BH horizon}} \ \leftrightarrow\ \{q_\Lambda, p^\Lambda\}$$

Flux vacua attractors

– IIB CY(3) orientifolds:

$N = 1$ SUGRA potential: $V = |DZ|^2 - 3|Z|^2, \quad Z = e^{K/2}W$

Ω - holomorphic 3-form of CY(3)

z^i - complex structure moduli

$$X^a(z) = \int_{A^a} \Omega\,, \qquad G_a(z) = \int_{B_a} \Omega$$

$$\rightarrow \qquad \Omega = X^a \alpha_a - G_a \beta^a$$

$$K = -\ln i \int \Omega \wedge \Omega = -\ln i(\bar{X}^a G_a - X^a \bar{G}_a)$$

– BH solutions in IIB on CY(3): H - NS 3-form flux

Central charge:

$$Z = e^{\frac{K}{2}} \int H \wedge \Omega$$

Expand H as:

$$H = p^a \alpha_a - q_a \beta^a \quad \text{or} \quad H = i[\bar{Z}\hat{\Omega} - K^{i\bar{j}}(D_{\bar{j}}\bar{Z})D_i\hat{\Omega}] + c.c. \ .$$

$$\hat{\Omega} = e^{\frac{K}{2}}\Omega$$

Susy minimum: $D_i Z = 0 \quad \rightarrow \quad H = i(\bar{Z}\hat{\Omega} - Z\bar{\hat{\Omega}})$

$$\Rightarrow \qquad p^a = i(\bar{Z}L^a - Z\bar{L}^a) \, . \ \ q_a = i(\bar{Z}M_a - Z\bar{M}_a)$$

(attractor equations)

– Flux vacua attractors:

RR and NS 3-form fluxes:

$$H = p_h^a \alpha_a - q_{ha}\beta^a \,, \qquad F = p_f^a \alpha_a - q_{fa}\beta^a$$

$N = 1$ theory:

$$W = \int (F - \tau H) \wedge \Omega = (q_{fa} - \tau q_{ha}) X^a - (p_f^a - \tau p_h^a) G_a$$

$$K = -\ln[-i(\tau - \bar{\tau})] - \ln[i \int \Omega \wedge \bar{\Omega}]$$

Central charge:

$$Z = e^{\frac{K}{2}} W = e^{\frac{K}{2}} \int [F \wedge \Omega + H \wedge (-\tau\Omega)]$$

Introduce:

$$F_4 = -\alpha \wedge F + \beta \wedge H\,, \qquad \int_{T^2} \alpha \wedge \beta = 1\,.$$

T^2 - auxiliary torus in F-theory description of IIB vacua

[i.e., as F-theory on $CY(4) = (CY(3) \times T^2)/\mathbb{Z}_2$]

Expansion:

$$F_4 = \bar{Z}\hat{\Omega}_4 - \bar{D}^A \bar{Z} D_A \hat{\Omega}_4 + \bar{D}^{0i} \bar{Z} D_{0i} \hat{\Omega}_4 + c.c.\,, \quad A = (0, i)$$

$$\Rightarrow \quad \begin{pmatrix} \mathcal{Q}_H \\ \mathcal{Q}_F \end{pmatrix} = \begin{pmatrix} 2\mathrm{Re}(\bar{Z}\mathcal{V}) \\ 2\mathrm{Re}(\tau \bar{Z}\mathcal{V}) \end{pmatrix} + \begin{pmatrix} 2\mathrm{Re}(\bar{Z}^{\underline{0}i} D_i \mathcal{V}) \\ 2\mathrm{Re}(\bar{\tau} \bar{Z}^{\underline{0}i} D_i \mathcal{V}) \end{pmatrix}.$$

$$\mathcal{Q}_H = (p_h^a, q_{ha})\,, \quad \mathcal{Q}_F = (p_f^a, q_{fa})\,, \quad \mathcal{V} = (L^a, M_a)$$

– Proof of new attractors:

Verify that New Attractor Equations $\Rightarrow$ $DZ = 0$:

- $D_i Z = 0$: due to special Kähler geometry of z^i
- $D_\tau Z = 0$: due to $(\tau - \bar{\tau}) K_\tau = -1$

$\Rightarrow$ Existing conjecture for heterotic attractors fails!

Rational for heterotic conjecture: 1 Kähler modulus t

$$W_{het} = \int (H - t\, d\omega) \wedge \Omega \quad \leftrightarrow \quad W_{IIB} = \int (F - \tau H) \wedge \Omega$$

plus special Kähler geometry; However: $K_{(t)} \neq K_{(\tau)}$!

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Generalizations

– Heterotic on $SU(3)$ structure manifolds:

Treat Kähler moduli similarly to complex ones, not to τ:

$$\Omega = X^{\mathcal{I}}(z)\alpha_{\mathcal{I}} - G_{\mathcal{I}}(z)\beta^{\mathcal{I}}\,, \qquad e^{-J_c} = X^{\mathcal{A}}(t)\omega_{\mathcal{A}} - G_{\mathcal{A}}(t)\tilde{\omega}^{\mathcal{A}}$$

$$L^{\mathcal{I}} = e^{K_\Omega/2}X^{\mathcal{I}}\,,\ \ M_{\mathcal{I}} = e^{K_\Omega/2}G_{\mathcal{I}}\,,\ \ L^{\mathcal{A}} = e^{K_J/2}X^{\mathcal{A}}\,,\ \ M_{\mathcal{A}} = e^{K_J/2}G_{\mathcal{A}}$$

$$W = \int (H + dJ_c)\wedge\Omega\,, \qquad J_c = B + iJ$$

$$Z = e^{(K_\Omega + K_J)/2}W \quad \longrightarrow \quad Z = m^{\mathcal{I}}_{\mathcal{A}}M_{\mathcal{I}}L^{\mathcal{A}} - e_{\mathcal{I}\mathcal{A}}L^{\mathcal{I}}L^{\mathcal{A}}\,.$$

Charges:

$$m^{\mathcal{I}}_{\mathcal{A}} = (-p^{\mathcal{I}}, m^{\mathcal{I}}_{\alpha}),\ \ e_{\mathcal{I}\mathcal{A}} = (-q_{\mathcal{I}}, e_{\mathcal{I}\alpha}),\ \ H = p^{\mathcal{I}}\alpha_{\mathcal{I}} - q_{\mathcal{I}}\beta^{\mathcal{I}},$$

Unlike CY(3):

$$d\omega_\alpha = m^{\mathcal{I}}_\alpha \alpha_{\mathcal{I}} - e_{\mathcal{I}\alpha}\beta^{\mathcal{I}}\,, \quad d\tilde{\omega}^\alpha = 0\,, \quad d\alpha_{\mathcal{I}} = e_{\mathcal{I}\alpha}\tilde{\omega}^\alpha\,, \quad d\beta^{\mathcal{I}} = m^{\mathcal{I}}_\alpha \tilde{\omega}^\alpha$$

$SU(3)$ structure - special case of $SU(3) \times SU(3)$ structure:

$$\mathcal{Q} = \begin{pmatrix} \tilde{m}^{\mathcal{I}\mathcal{A}} & m^{\mathcal{I}}_{\mathcal{A}} \\ \tilde{e}^{\mathcal{A}}_{\mathcal{I}} & e_{\mathcal{I}\mathcal{A}} \end{pmatrix} \quad \text{with} \quad \tilde{m}^{\mathcal{I}\mathcal{A}} = 0 = \tilde{e}^{\mathcal{A}}_{\mathcal{I}}$$

Introduce doubled section: $\hat{\mathcal{V}} = e^{(K_\Omega + K_J)/2}\left(\Omega \otimes e^{-J_c}\right)$

$$? \quad \mathcal{Q} = 2\mathrm{Re}(\bar{Z}\hat{\mathcal{V}} + g^{i\bar{j}} g^{\alpha\bar{\beta}}\, D_i D_\alpha \hat{\mathcal{V}}\, \bar{D}_{\bar{j}} \bar{D}_{\bar{\beta}} \bar{Z})$$

Turns out: ONLY for $Z = 0$ there are attractor equations!

Attractors for Minkowski vacua: $\mathcal{Q} = 2\mathrm{Re}(g^{i\bar{j}} g^{\alpha\bar{\beta}}\, D_i D_\alpha \hat{\mathcal{V}}\, \bar{D}_{\bar{j}} \bar{D}_{\bar{\beta}} \bar{Z})$

– Type II on $SU(3) \times SU(3)$ structure spaces:

$SU(3) \times SU(3)$ structure: characterized by (Φ_-, Φ_+)

[reduces to (Ω, e^{-J_c}) for $SU(3)$ structure]

$$\Phi_- = X^{\mathcal{I}}(z)\alpha_{\mathcal{I}} - G_{\mathcal{I}}(z)\beta^{\mathcal{I}}\,, \quad \Phi_+ = X^{\mathcal{A}}(t)\omega_{\mathcal{A}} - G_{\mathcal{A}}(t)\tilde{\omega}^{\mathcal{A}}$$

$$K_-(z) = -\ln i \int \langle \Phi_-, \bar{\Phi}_- \rangle\,, \quad K_+(t) = -\ln i \int \langle \Phi_+, \bar{\Phi}_+ \rangle$$

Both K_-, K_+: special Kähler metrics

$$\mathcal{D}\omega_{\mathcal{A}} = m^{\mathcal{I}}_{\mathcal{A}}\alpha_{\mathcal{I}} - e_{\mathcal{I}\mathcal{A}}\beta^{\mathcal{I}}\,, \quad \mathcal{D}\tilde{\omega}^{\mathcal{A}} = \tilde{m}^{\mathcal{I}\mathcal{A}}\alpha_{\mathcal{I}} - \tilde{e}^{\mathcal{A}}_{\mathcal{I}}\beta^{\mathcal{I}}$$
$$\mathcal{D}\alpha_{\mathcal{I}} = -\tilde{e}^{\mathcal{A}}_{\mathcal{I}}\omega_{\mathcal{A}} + e_{\mathcal{I}\mathcal{A}}\tilde{\omega}^{\mathcal{A}}\,, \quad \mathcal{D}\beta^{\mathcal{I}} = -\tilde{m}^{\mathcal{I}\mathcal{A}}\omega_{\mathcal{A}} + m^{\mathcal{I}}_{\mathcal{A}}\tilde{\omega}^{\mathcal{A}}$$

Generically: two internal spinors $\Rightarrow$ $N = 2$ effective theory

Unlike CY(3):

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$$\mathcal{D}\alpha_{\mathcal{I}} = -\tilde{e}^{\mathcal{A}}_{\mathcal{I}}\omega_{\mathcal{A}} + e_{\mathcal{I}\mathcal{A}}\tilde{\omega}^{\mathcal{A}}\,, \quad \mathcal{D}\beta^{\mathcal{I}} = -\tilde{m}^{\mathcal{I}\mathcal{A}}\omega_{\mathcal{A}} + m^{\mathcal{I}}_{\mathcal{A}}\tilde{\omega}^{\mathcal{A}}$$

Generically: two internal spinors $\Rightarrow$ $N = 2$ effective theory

- $N = 1$ truncation:

  [orientifolding, spontaneous partial susy breaking]

Consider type IIA: (no RR fluxes)

$$W = c \int \langle \Phi_+, \mathcal{D}\Pi_- \rangle \,, \quad \Pi_- = A^{odd}_{RR} + i\,\mathrm{Im}(c' e^{-\phi}\,\Phi_-)$$

Expand: $\Pi_- = \hat{X}^{\mathcal{I}} \alpha_{\mathcal{I}} - \hat{G}_{\mathcal{I}} \beta^{\mathcal{I}} \quad \longrightarrow$

$$Z = e^{K/2} W = c \left[e_{\mathcal{I}\mathcal{A}} \hat{L}^{\mathcal{I}} L^{\mathcal{A}} - m^{\mathcal{I}}_{\mathcal{A}} \hat{M}_{\mathcal{I}} L^{\mathcal{A}} - \tilde{e}^{\mathcal{A}}_{\mathcal{I}} \hat{L}^{\mathcal{I}} M_{\mathcal{A}} + \tilde{m}^{\mathcal{I}\mathcal{A}} \hat{M}_{\mathcal{I}} M_{\mathcal{A}} \right]$$

Problem: $\hat{K}_- = -2 \ln i \left(\bar{\hat{X}}^{\mathcal{I}} \hat{G}_{\mathcal{I}} - \hat{X}^{\mathcal{I}} \bar{\hat{G}}_{\mathcal{I}} \right)$ - NOT special Kähler

[$\{\hat{X}^{\mathcal{I}}, \hat{G}_{\mathcal{I}}\}$ - independent]

Susy conditions: $D_{t^\alpha} Z = 0, \quad D_{\hat{X}^{\mathcal{I}}} Z = 0, \quad D_{\hat{G}_{\mathcal{I}}} Z = 0$

Nevertheless: $\exists$ Minkowski attractors!

Introduce: $\mathcal{U} = e^{(\hat{K}_- + K_+)/2} (\Pi_- \otimes \Phi_+)$

$$\mathcal{Q} = c^{-1}\, 2\,\mathrm{Re}(g^{\hat{i}\bar{\hat{j}}} g^{\alpha\bar{\beta}}\, D_{\hat{i}} D_\alpha \mathcal{U}\, \bar{D}_{\bar{\hat{j}}} \bar{D}_{\bar{\beta}} \bar{Z})\,, \quad \hat{i} \to \{\hat{X}^{\mathcal{I}}, \hat{G}_{\mathcal{I}}\}$$

Type IIB: obtained from type IIA by $\Phi_+ \to \Phi_-$, $A^{odd}_{RR} \to A^{ev}_{RR}$

$$\to \quad W = c \int \langle \Phi_-, \mathcal{D}\Pi_+ \rangle\,, \quad \Pi_+ = A^{ev}_{RR} + i\,\mathrm{Im}(c' e^{-\phi}\, \Phi_+)$$

$\Rightarrow$ Minkowski attractors for type IIB as well!

Including RR fluxes:

$$W_{\mathrm{IIA}} = c \int \langle \Phi_+, \mathcal{D}\Pi_- + G^{ev}_{RR} \rangle \quad : \quad \mathcal{Q} \to \mathcal{Q} + \mathcal{Q}_{RR} \quad (?)$$

Summary

- Flux vacua attractors:
  - Verified Kallosh's new attractors (for IIB CY(3) orientifolds)
  - Disproved proposed generalizations (heterotic on $SU(3)$ str.)
  - Found Minkowski attractors:
    - Heterotic on $SU(3)$ structure
    - Type IIA/B on $SU(3) \times SU(3)$ structure
- Open issues:
  - Why no AdS attractors?
  - Nonsupersymmetric attractors?
  - Inclusion of RR flux
  - Implications for moduli stabilization