COSTAS MEMORIAL DAY

Carlo Angelantonj
(UNITO & INFN)

My first encounter with Costas was … with his dark and deep voice

THE JOY OF LIFE

THE JOY OF DOING PHYSICS

THE JOY OF BEING WITH FRIENDS

THE JOY OF HIS LAND

THE JOY OF SHARING HIS PASSIONS

Costas 60s in Cyprus

Never … ever … give up!

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Resolution of Hagedorn singularity in superstrings with gravito-magnetic fluxes

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(Thermal) Supersymmetry Breaking in Type II Superstrings

They afford a richer pattern than heterotic strings since

$$(-1)^{F_{\rm st}} = (-1)^{F_{\rm L}+F_{\rm R}}$$

We use this fact, to choose the thermal/Scherk-Schwarz breaking

$$\mathbb{Z}_2 \times \mathbb{Z}_2$$

$$(-1)^{F_{\rm L}}\,\delta_1 \qquad\qquad (-1)^{F_{\rm R}}\,\delta_2$$

($\delta_{1,2}$ shifts along two different directions)

(Thermal) Supersymmetry Breaking in Type II Superstrings

$$\mathcal{Z} = \Big[V_8\, \Gamma^{(1)}_{m,2n} - S_8\ \Gamma^{(1)}_{m+\frac{1}{2},2n} + O_8\, \Gamma^{(1)}_{m+\frac{1}{2},2n+1} - C_8\, \Gamma^{(1)}_{m,2n+1} \Big] \times \Big[\bar{V}_8\, \Gamma^{(2)}_{m,2n} - \bar{S}_8\ \Gamma^{(2)}_{m+\frac{1}{2},2n} + \bar{O}_8\, \Gamma^{(2)}_{m+\frac{1}{2},2n+1} - \bar{C}_8\, \Gamma^{(2)}_{m,2n+1} \Big]$$

All fermions and RR states are massive, and tachyons are absent

$$2\, m^2_{O\bar{O}} = \left(\frac{1}{\sqrt{2}R_1} - \sqrt{2}R_1 \right)^2 + \left(\frac{1}{\sqrt{2}R_2} - \sqrt{2}R_2 \right)^2$$

The model enjoys T-duality: $\sqrt{2}R \to 1/\sqrt{2}R$

THERMAL INTERPRETATION

In the Lagrangian representation the shift

$$\tilde{m}_1 \to \tilde{m}_1 + \tilde{m}_0\,, \qquad n_1 \to n_1 + n_0$$

results into the GSO phase

$$(-1)^{\tilde{m}_0(a+\bar{a})+n_0(b+\bar{b})}\,(-1)^{\tilde{m}_1\bar{a}+n_1\bar{b}+\tilde{m}_1 n_1}$$

canonical temperature

breaks $\mathcal{N}=(4,4)\to\mathcal{N}=(4,0)$

$$\mathcal{Z}(\beta)=\mathrm{tr}\ e^{-\beta H}e^{2\pi i(GQ_+-BQ_-)}\Big|_{G=1,B=\frac{1}{2}}$$

THERMAL INTERPRETATION

The complete partition function for the *N*=(4,0) theory reads then

$$\mathcal{Z}(\beta) = \text{tr}\ e^{-\beta H} e^{2\pi i (G Q_+ - B Q_-)}\Big|_{G=1, B=\frac{1}{2}}$$

It is free of Hagedorn instabilities, and enjoys a temperature duality

$$\mathcal{Z}(T/T_{\rm H}) = \mathcal{Z}(T_{\rm H}/T)$$

(Thermal) Supersymmetry Breaking in Type II Superstrings

Something interesting happens at the self-dual point $\sqrt{2}R_{1,2} = 1$

$$\mathcal{Z} = \left[V_8\, \mathit{\Gamma}^{(1)}_{m,2n} - S_8\, \mathit{\Gamma}^{(1)}_{m+\frac{1}{2},2n} + O_8\, \mathit{\Gamma}^{(1)}_{m+\frac{1}{2},2n+1} - C_8\, \mathit{\Gamma}^{(1)}_{m,2n+1} \right] \times \left[\bar{V}_8\, \mathit{\Gamma}^{(2)}_{m,2n} - \bar{S}_8\, \mathit{\Gamma}^{(2)}_{m+\frac{1}{2},2n} + \bar{O}_8\, \mathit{\Gamma}^{(2)}_{m+\frac{1}{2},2n+1} - \bar{C}_8\, \mathit{\Gamma}^{(2)}_{m,2n+1} \right]$$

The vectors $V\bar{O}$ and $O\bar{V}$ are now level matched

and the “graviphotons” have the enhanced gauge symmetry

$$SO(4)_{\mathrm{L}} \times SO(4)_{\mathrm{R}}$$

(This is possible because of the asymmetry nature of the construction)

ADDING O-PLANES AND D-BRANES

Something ***more*** interesting happens is we orientifold this model

$$\mathcal{A} \supset N^2 \sum_{m,n} \left[(V_6 O_2 + O_6 V_2) q^{\frac{1}{2}\left(\frac{m}{\sqrt{2}R}\right)^2 + \frac{1}{2}(n\sqrt{2}R)^2} + O_6 O_2 q^{\frac{1}{2}\left(\frac{m+1/2}{\sqrt{2}R}\right)^2 + \frac{1}{2}((n+1/2)\sqrt{2}R)^2} \right]$$

$$\mathcal{M} \supset -N \sum_{m,n} \left[(V_6 O_2 - O_6 V_2)(-1)^{m+n} q^{\frac{1}{2}\left(\frac{m}{\sqrt{2}R}\right)^2 + \frac{1}{2}(n\sqrt{2}R)^2} - O_6 O_2 q^{\frac{1}{2}\left(\frac{m+1/2}{\sqrt{2}R}\right)^2 + \frac{1}{2}((n+1/2)\sqrt{2}R)^2} \right]$$

At the self-dual point, the scalars living on the D-branes are charged with respect to the (diagonal) closed-string gauge group $SO(4)$ **!**

$$(\mathbf{6}, \mathbf{136}) \quad \text{of} \quad SO(4)_{\text{closed}} \times SO(16)_{\text{open}}$$

Never seen before … or after

GOOD BYE COSTAS