Through the looking glass: the world at small length scales

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Brief Curriculum Vitae – Suresh Govindarajan

Education

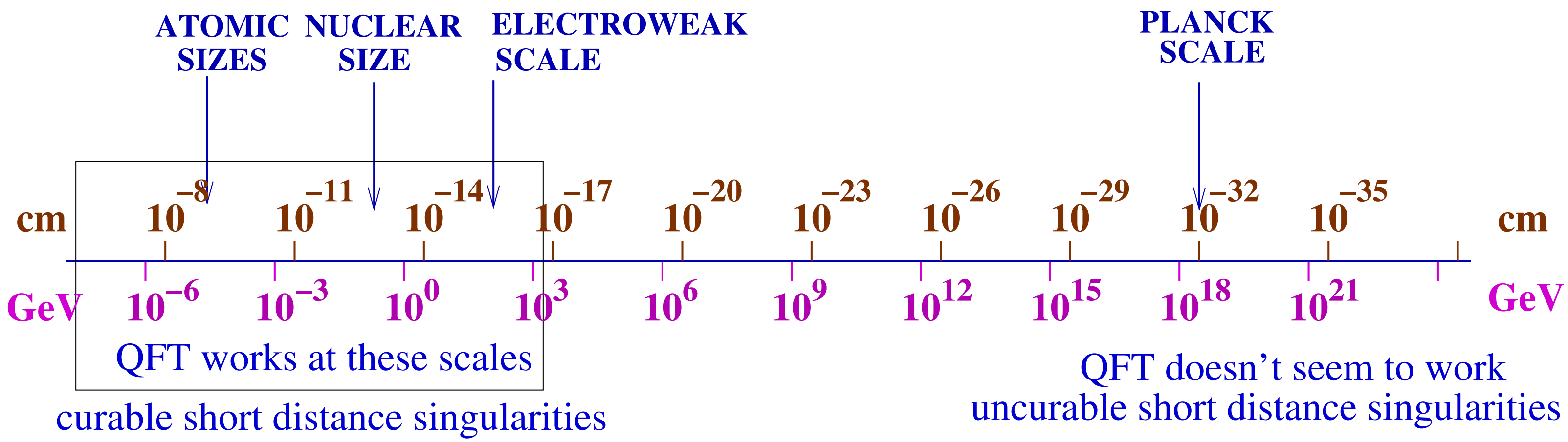
- **1986** B.Tech. (Elec. & Electronics Engg.), IIT Madras
- **1991** Masters and Ph.D. (Theoretical Physics), U. of Pennsylvania

Work Experience

- **91-93** Postdoctoral Fellow, Inst. of Math. Sciences, Chennai
- **93-95** Postdoctoral Fellow, Tata Inst. of Fund. Res., Mumbai
- **97** Alexander von Humboldt Fellow, U. of Bonn
- **95-03** Assistant Professor, Dept. of Physics, IIT Madras

Research Interests Quantum Field Theory; Superstring Theory; Conformal Field Theory; Supersymmetric Solitons & D-branes; Geometric Aspects of String Theory.

Fundamental length scales

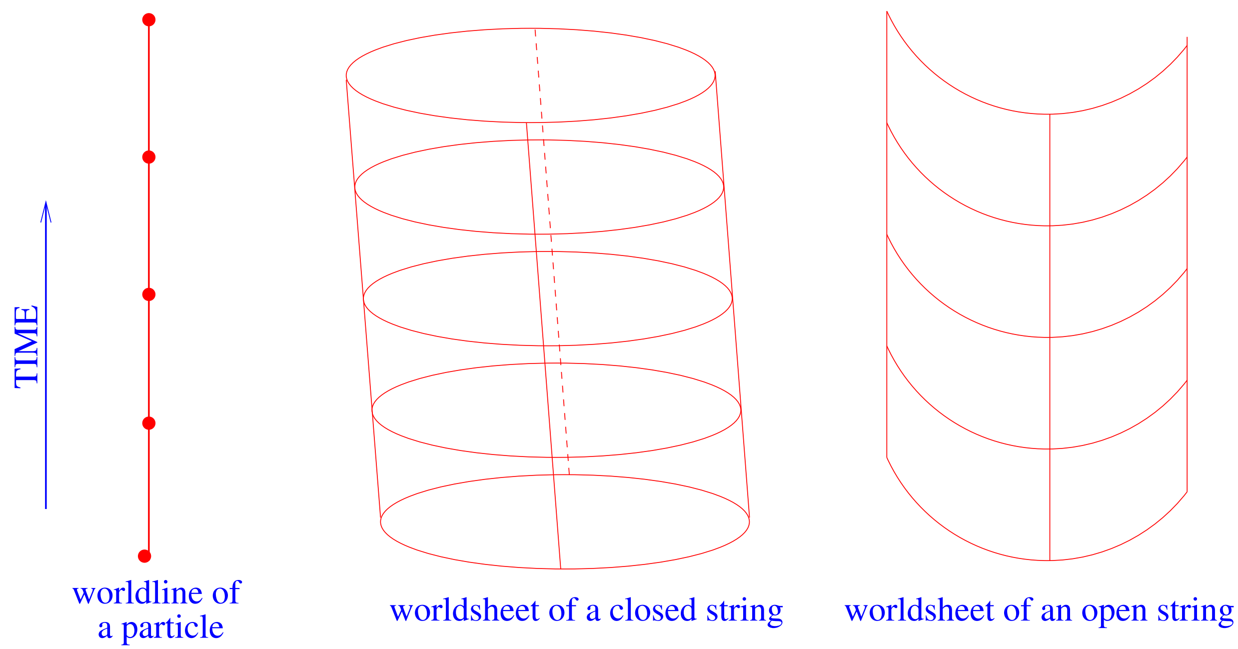


Planck length: $l_p = \sqrt{\frac{G_N h}{c^3}}$

An expectation: Just as quantum mechanics has modified many of our classical notions, quantum gravity must change our notions of spacetime itself at a length scale of order l_p.

The need for string theory

If fundamental objects were strings rather than particles, then the string scale l_s acts as a cut-off at small length scales



A surprise: The quantum superstring needs a ten-dimensional spacetime.

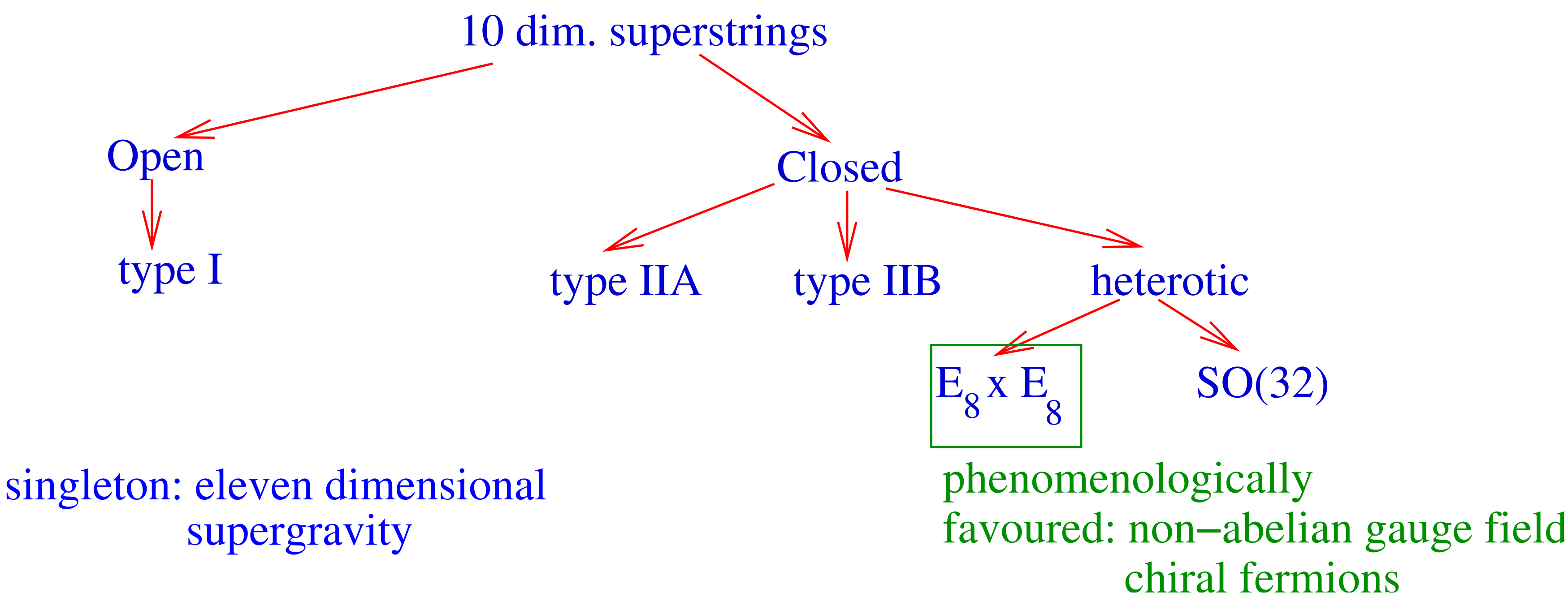
Hidden spatial dimensions?

- Kaluza and Klein: Consider a five-dimensional spacetime, the extra dimension being a circle of radius R.
- Quantum mechanics implies that momentum along this fifth direction must be quantised in units of $\hbar/R$.
- As $R \to 0$, the smallest non-zero momentum (and energy) is very large.
- It is thus experimentally possible that there are six extra dimensions which are not visible even at ~ 1TeV.

Conclusion: The invisible dimensions may be a compact six-dim. manifold such as a Calabi-Yau manifold (CY3).

Five different superstrings:

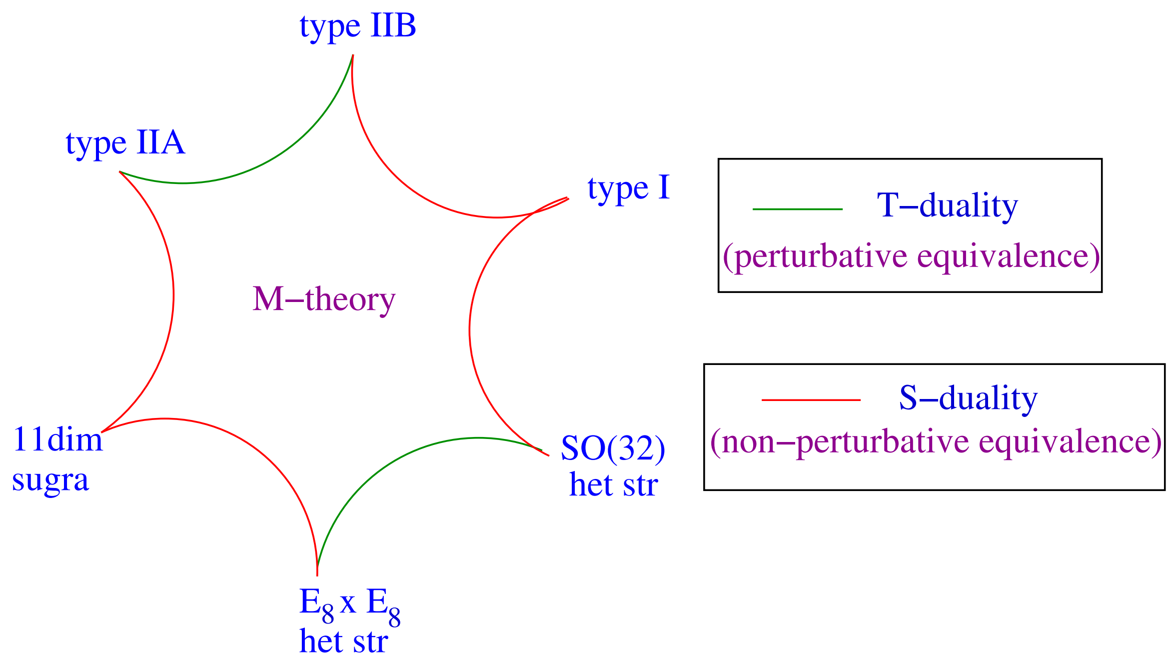
Superstring theory in 1991



Apriori, they all seem unrelated. But this picture has significantly changed.

M(ysterious,other)-theory

Superstring theory today



There exist dualities, S− and T− dualities which relate these seemingly different theories!

The dimension of spacetime is a dynamical issue!

My research

My research in the past few years has been on

D-branes on Calabi-Yau manifolds

The results can be broken up in the following categories:

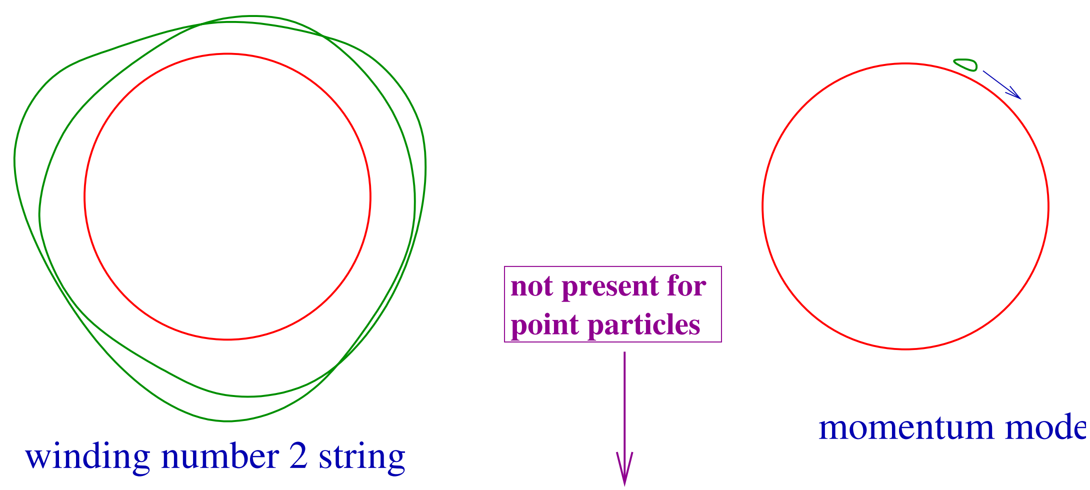
- Supersymmetric boundary conditions in CFT
- Spectra of stable D-branes
- Superpotentials on the world volume of D-branes
- $\mathcal{N} = 1$ supersymmetric compactifications from orientifolds
- Spacetime as seen by various D-brane probes

T-duality

type IIA string on a circle of radius R

$$\widetilde{R} = l_s^2/R \qquad \updownarrow \qquad \text{T-duality}$$

type IIB string on a circle of radius $\widetilde{R}$



$$E^2 = \left(\frac{n}{R}\right)^2 + \left(\frac{wR}{l_s^2}\right)^2 + \cdots = \left(\frac{n}{R}\right)^2 + \left(\frac{w}{\widetilde{R}}\right)^2 + \cdots$$

Under T-duality: momentum modes $\leftrightarrow$ winding modes.

S-duality

- Maxwell's equations exhibit an unusual symmetry:

$$(\vec{E},\vec{B}) \rightarrow (\vec{B},-\vec{E}) \quad , \quad (\rho_e,\vec{J}_e) \rightarrow (\rho_m,\vec{J}_m)$$

$$e \rightarrow 1/e \quad \text{weak} \rightarrow \text{strong coupling}$$

  Elec. charged objects become mag. charged.

- More general examples admit **solitonic** solutions that are magnetically charged [monopoles, dyons] suggesting

$$\boxed{\text{fundamental particles}} \longleftrightarrow \boxed{\text{solitons}}$$

- The type I string is S-dual to the SO(32) het. string, the fundamental string of the het. str. appears as a solitonic string in type I string theory.

Solitons in 10 dim type II strings

- String theory admits solitonic solutions that are p-branes. These are objects extended in $(p+1)$ dimensions.
- E.g. $p = 0$ is a particle and $p = 1$ is a string. All string theories admit string-like solitons as well as NS 5-branes.
- Further, the type IIA string has Dp-branes for $p = 0, 2, 4, 6, 8$ and the type IIB string has Dp-branes for $p = -1, 1, 3, 5, 7, 9$.
- Dp-branes are charged under $(p+1)$-form gauge fields that appear in the RR sector. [Definition 1]
- S- and T-dualities suggest that we should treat these solitons on par with the fundamental string – p-brane democracy [Townsend]

D-branes – Definition 2

- It is a conformally invariant boundary condition for an open-string[Polchinski]. It picks out a submanifold C of spacetime M, where open-strings can end.
- A one-loop comp. by Leigh showed that conformal invariance for b.c.'s imply (higher loop corrections with Madhu)

$$\beta(u^i) \propto h^{ab} K^i_{ab} = 0$$

  u^i – normal deformations of C in M, h_{ab} and K^i_{ab}– induced metric and extrinsic curvature on C
- Thus, the vanishing of the beta function implies that C must be a minimal submanifold of M.
- Relating the two definitions has led to several interesting relationships – open-closed dualities

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Boundary conditions in CFT

This work appeared in these papers

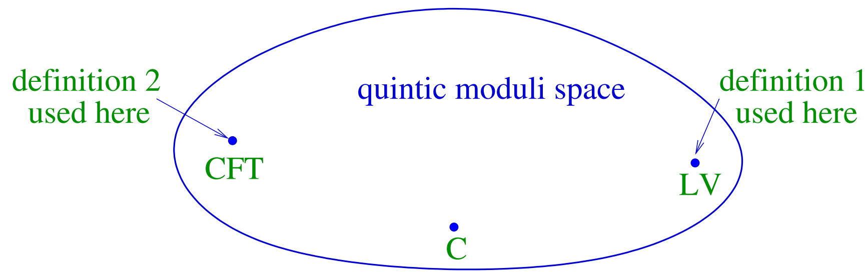
(i) Nucl.Phys.B **580** (2000) 519-547 [hep-th/9907131](with Jayaraman & Sarkar);
(ii) JHEP **0007**:016,2000. [hep-th/0003242](with Jayaraman);
(iii) Nucl.Phys.B **593** (2001) 155-182 [hep-th/0007075](with Jayaraman & Sarkar);
(iv) Nucl.Phys.B **618** (2001) 50-80 [hep-th/0104126](with Jayaraman)

We constructed boundary conditions for four-dim. compactifications on CY manifolds. We constructed D-branes in Gepner models, LG models as well as the gauged linear sigma model. The last model enabled us to interpolate between different descriptions. Paper (i) was one of the first papers to provide geometric identifications for D-branes in Gepner models.

D-brane spectra

(v) Nucl.Phys.B **600** (2001) 457-486 [hep-th/0010196] (with Jayaraman);

(vi) Proc. Strings 2001 [hep-th/0105216] (with Jayaraman).



In this paper, we established a correspondence holds between D-branes in CFT and D-branes at large volume. The precise statement is that D-branes are stable representations of a quiver, the McKay quiver in CFT and the Beilinson quiver at LV. This encodes details about how the spectrum changes as the size of the CY3 changes.

Superpotentials on D-branes

(vii) Nucl.Phys.B **646** (2002) 498-523 [hep-th/0108234] (with Jayaraman & Sarkar);

(viii) Comm. Math. Phys (to appear) [hep-th/0203173] (with Douglas(Rutgers), Jayaraman,Tomasiello(Ecole Poly.)).

In paper (vii) above, we showed that the quantum corrected superpotential satisfies a Picard-Fuchs type differential equation. The solution of the diff. eqn. gave the superpotential including non-perturbative corrections (worldsheet instantons).

In paper (viii), we show how the complex moduli (shape) of a CY3 modify the superpotential by an explicit computation in topological string theory. This has interesting relation to deformation theory of A_∞-algebras.

$\mathcal{N} = 1$ compactification in 4D

(ix) submitted for publication [hep-th/0306257] (Jun 2003) (with Majumder(Rutgers))

(x) manuscript under preparation (with Jayaraman)

Type II compactifications on CY3 give rise to $\mathcal{N} = 2$ supersymmetry in four dimensions. In the above two papers, I have used a method called orientifolding to reduce supersymmetry to $\mathcal{N} = 1$. In paper (ix), we provided a CFT construction that is dual to M-theory compactified on a seven-dim. manifolds with G_2 holonomy.

However, supersymmetry is broken in the real world – LHC?

D-branes as probes of spacetime

(xii) Phys.Rev.D **56** (1997)5276-5278
(xiii) Nucl.Phys.B **507** (1997) 589-608
(xiv) work in progress (with Madhu & Ray (IACS))

The worldvolume theories of D-branes, in particular, their moduli spaces provide information about the space they move in. Matrix theory is one such proposal which uses D0-branes as a probe. Papers (xii) and (xiii) dealt with Matrix theory for six-dim. I am currently trying to understand the case for four-dim. compactifications on CY3.

In (xiv) mentioned above, we are comparing the spacetime metric as seen by the fundamental string, D0-branes as well as other probes by explicitly computing them.