Holography, Supergravity and String Theory

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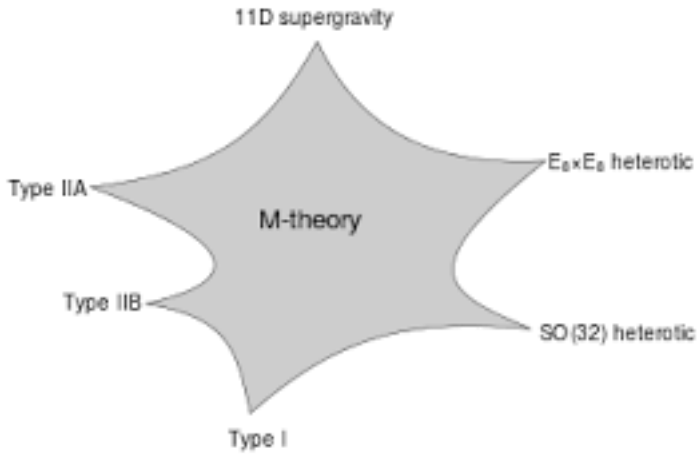

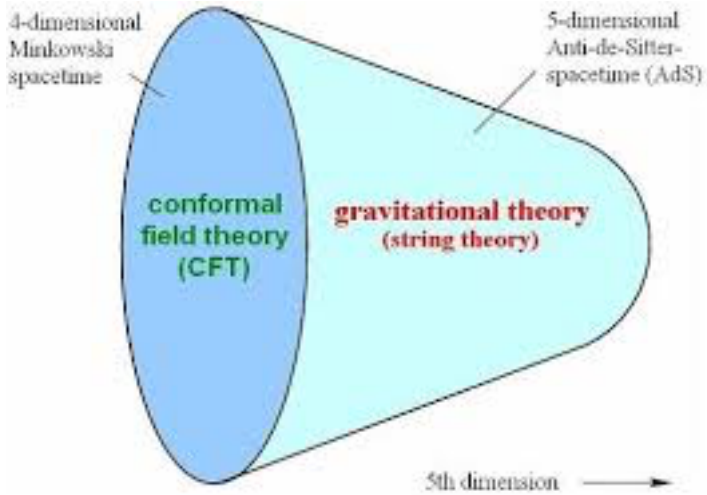

ICTEA Days 2025

String Theory: Most consistent theory unifying Quantum Gravity and the Standard Model of particle interactions

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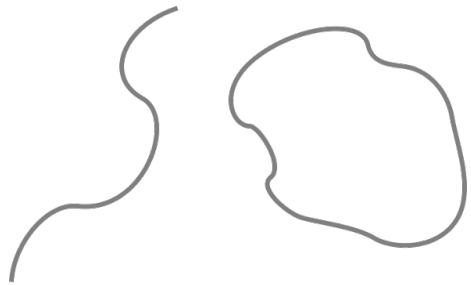
STRING THEORY IS

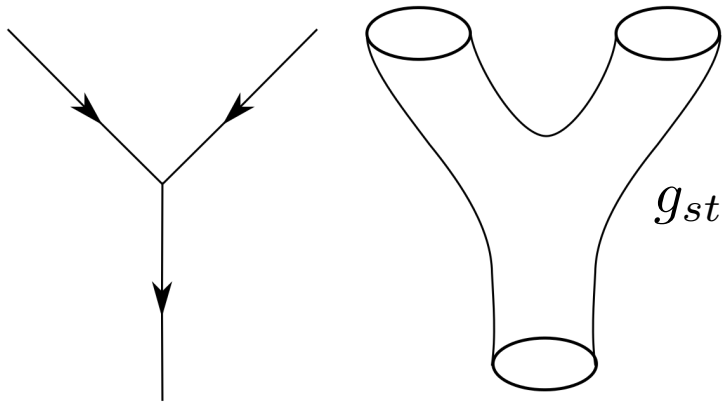
String Theory basics

Idea: With sufficient resolution all elementary particles are one dimensional objects (strings)



Typical size: $l_p \sim 10^{-33} cm$ (string length)

Interactions: Joining and splitting of strings



Particles: Vibrating modes of the string

The graviton appears as a vibrating mode!

Even more:

General Relativity arises at distances $l >> l_s$ (field theory limit)

$$\boxed{R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu}}$$

This sets the string length: $l_s \approx \sqrt{\frac{G\hbar}{c^3}} = 10^{-33} cm$

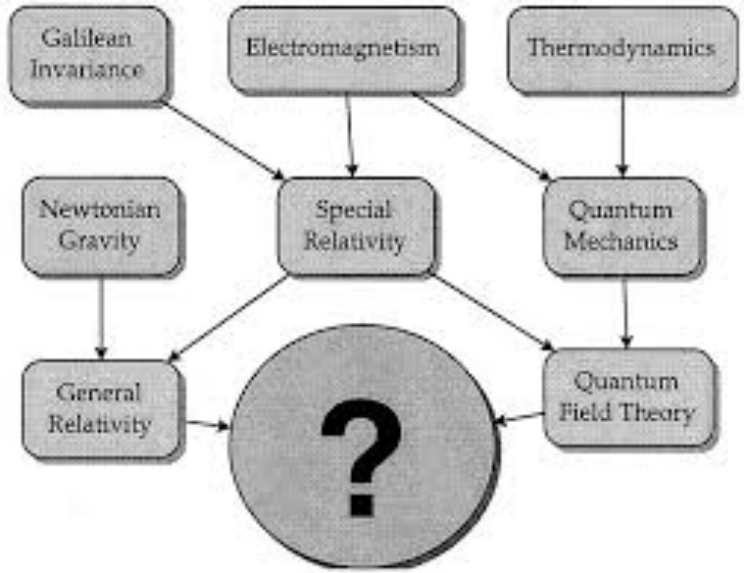
(Planck scale)

But now the spatial extent of the string provides a UV cut-off, and the UV divergences that appear when one tries to quantize gravity disappear!

From open strings: Gauge theory

String Theory: Finite theory that contains both gauge theories and gravity, both undisputed properties of nature!

→ Candidate to unify all fundamental forces



Why do we want a theory of everything?

Because we want to understand black holes and the Universe shortly after the Big-Bang

Supersymmetry is needed to include fermions

Supersymmetry is a *prediction* of String Theory, at least at the Planck scale

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Supersymmetry is a *prediction* of String Theory, at least at the Planck scale

Supergravities: Field theories that combine gravity with supersymmetry

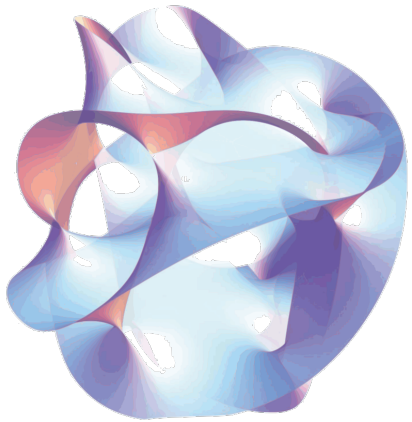
Proposed in the past as Theories of Unification

Sugra field theories are the low energy limit of Superstring theories

As a Theory of Everything String Theory predicts the dimensions of spacetime: 10

6 extra dimensions need to be compactified:

Richness of 4d physics $\leftrightarrow$ Geometry of 6d space



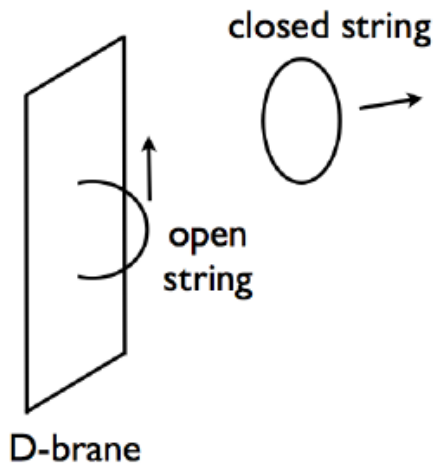
Cross section of
Calabi-Yau manifold

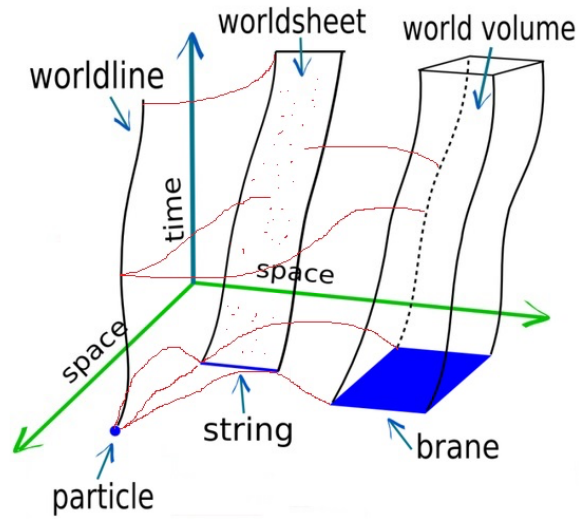
However,

Infinitely many vacua $\longrightarrow$ Landscape / Swampland

Holography

String theory is more than a theory of strings



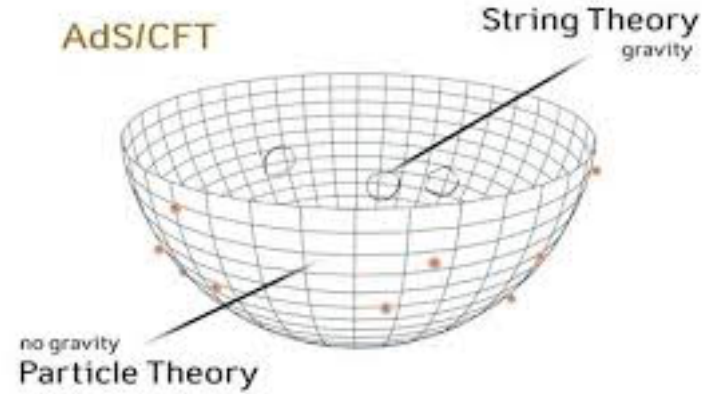


D-branes have a dual description that has brought about the most important developments in String Theory in the last 25 years:

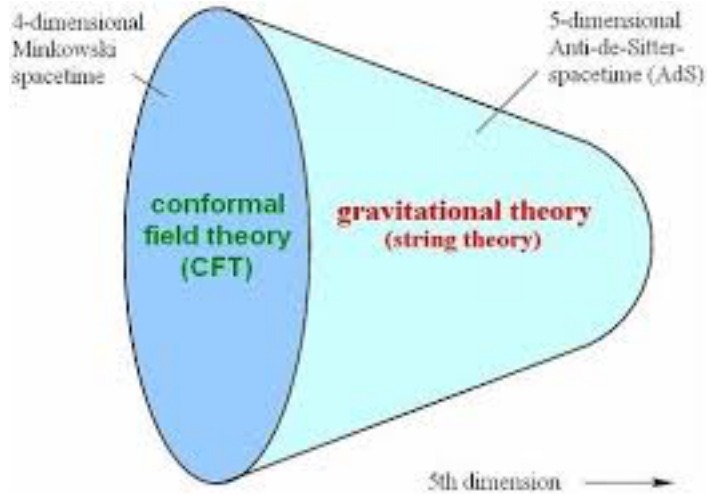
- AdS/CFT correspondence
- Black Hole thermodynamics

The AdS/CFT correspondence

Equivalence between string theory in the space around D-branes (AdS) and the gauge theory that lives in them (a CFT)



10d string theory dual to a 4d gauge theory!



Strong/weak coupling duality!

Applications:

Mostly used to gain information about strongly interacting gauge theories (QCD!)

Universal predictions for the transport coefficients of a gauge-theory plasma, fluid dynamics, condensed matter

More fundamentally,

Spacetime arising as an emergent phenomenon from the entanglement of the quantum states in the gauge theory

Black Holes

Black Holes: Thermodynamical systems with temperature and entropy

$$S = \frac{A}{4G}$$

Proportional to the area of the horizon!

Holographic principle: The degrees of freedom of quantum gravity in a region can be encoded on the boundary of that region

AdS/CFT provides an explicit realization

Microscopical description of entropy:

Intersecting D-brane configuration describing a black hole as supergravity solution:

$$S \sim A$$

As the end points of open strings the D-branes are described by a field theory, and one can compute the number of states:

$$S_{\text{open}} \sim \ln \Omega$$

$$S_{\text{closed}} = 2\pi\sqrt{Q_m(\frac{1}{2}Q_e^2+1)} \quad , \quad S_{\text{open}} = 2\pi\sqrt{\frac{1}{2}Q_m Q_e^2+1}$$

Perfect agreement when $Q_e >> 1$!

Great success of String Theory!

The members of the group develop their research along these lines:

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L1: SUGRA: solutions, Black Holes

A. Guarino, Y. Lozano, N. Macpherson, P. Meessen

L2: QFT vs Gravity, Swampland

A. Guarino, Y. Lozano, D. Rodriguez-Gomez, P. Soler

L3: Applications of AdS/CFT to realistic systems

A. Faedo, C. Hoyos, D. Musso

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City College NY, U. Libre de Bruxelles, Vrije U. Brussels, Leuven U, Leiden U, Utrecht U, Goteborg U, Helsinki U, Imperial College, Queen Mary College, Swansea U, Humboldt U, U. Milano, U. Milano-Bicocca, ENS Lyon, ENS Paris, E. Polytechnique, Technion U, Tel Aviv U, Ben Gurion U…

- **N=6 supersymmetric $AdS_2 \times \mathbb{CP}^3 \times \Sigma_2$**
  A. Conti, Y. Lozano, N. Macpherson
  FPAUO-25/05, arXiv:2503.23585.
- **On $AdS_2 \times S^7$, its $\mathbb{Z}_k$ orbifold and their dual quantum mechanics**
  Y. Lozano, N. Macpherson, A. Passias
  FPAUO-25/04, arXiv:2503.23227.
- **Fracton gauge theories in curved spacetime**
  E. Afxonidis, A. Caddeo, C. Hoyos, D. Musso
  Phys. Rev. D 111 (2025) 10, 105023 [FPAUO-25/03, arXiv:2503.08621].
- **Continuous symmetry defects and brane/anti-brane systems**
  H. Calvo, F. Mignosa, D. Rodríguez-Gómez
  FPAUO-25/02, arXiv:2503.04892.
- **Light dilaton near critical points in top-down holography**
  D. Elander, A. Faedo, M. Piai, R. Rodgers, J. Subils
  FPAUO-25/01, arXiv:2502.19226.
- **Komar charge of N=2 supergravity and its superspace generalization**
  I. Bandos, P. Meessen, T. Ortín
  J. High Energ. Phys. 05 (2025) 231 [FPAUO-24/26, arXiv:2412.18510].
- **Circle compactifications of Minkowski$_D$ solutions, flux vacua and solitonic branes**
  N. Macpherson, P. Merrikin, R. Stuardo
  FPAUO-24/25, arXiv:2412.15102.
- **The boundary entropy function for interface conformal field theories**
  E. Afxonidis, A. Karch
  FPAUO-24/24, arXiv:2412.05381.


THANKS!