String Theory Group

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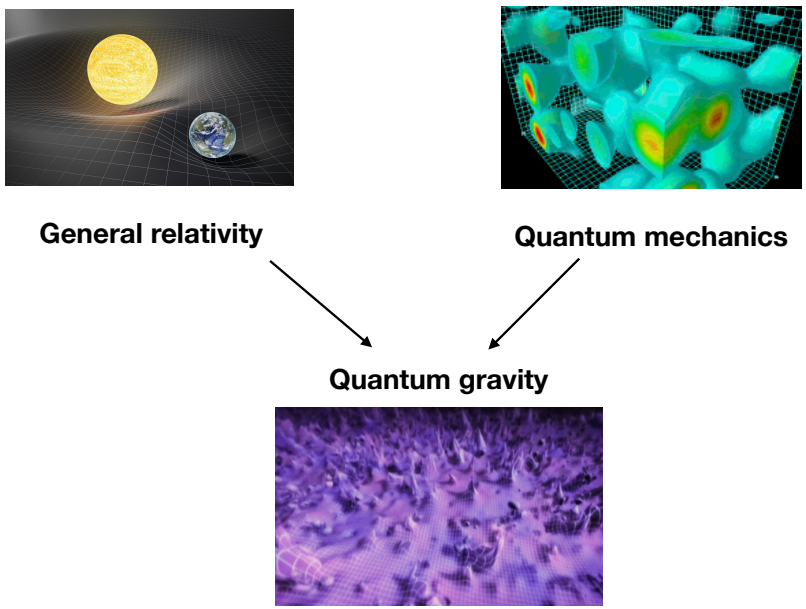
Towards the unification

- Quantum mechanics successfully explains small objects, such as atoms, nuclei and particles.
- Einstein's theory of gravity, known as general relativity, successfully describes behaviour of massive objects, such as stars and galaxies.
- To understand several problems of black holes and the early Universe, one needs the unification of these two theories, known as quantum gravity.



[Picture credit: wikipedia]

What is string theory?

- String theory is an attempt to unify the **theory of gravity** and the **theory describing elementary particles** in a single framework.
  - Gravity is described by general relativity.
  - The theory that describes small particles is quantum mechanics. When particles are moving close to the speed of light, quantum mechanics needs to be unified with special relativity. The theory that describes high energy particle interactions is quantum field theory.
- According to this theory, matter does not consist of point-particles but rather of tiny strings (around 10^{-33} cm).

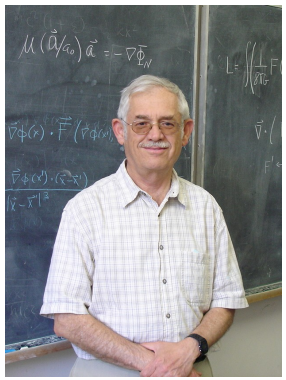
Why string theory?

1. String theory is a theory of quantum gravity.
2. String theory provides new perspectives on quantum field theory.
3. String theory provides new results in mathematics.

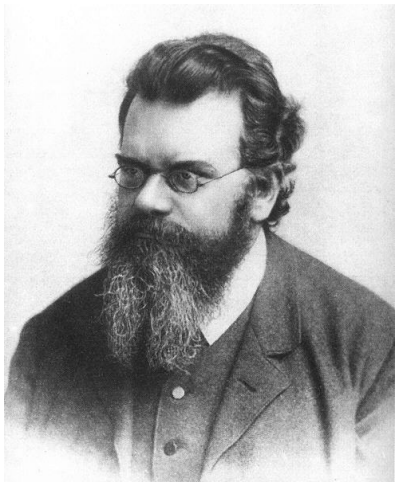
In this talk, we will focus on the first two points.

String theory as a theory of quantum gravity

- In general relativity, a black hole is a region of spacetime in which the gravity is so strong that no particle or radiation can escape.
- However, in 1974 Hawking showed that, as a result of quantum mechanics, **black holes emit radiation** like hot objects with a certain temperature.
- Along with the work of Bekenstein in 1973, Hawking showed that the black hole entropy is proportional to its area.



String theory as a theory of quantum gravity



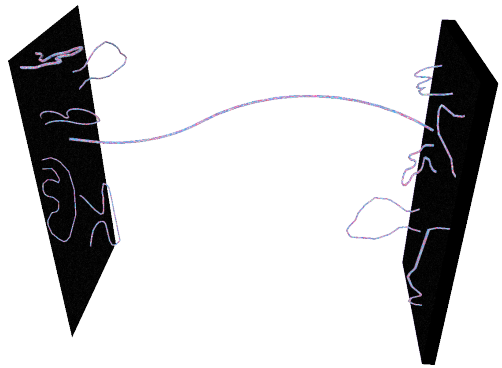
Boltzmann: Entropy is a measure of the randomness or disorder of a physical system. The entropy of a system of gas is the log of the number of different states of the molecules (microscopic degrees of freedom).

Big question: What's the microscropic origin of the black hole entropy?

String theory as a theory of quantum gravity

In 1996, Strominger and Vafa derived the Bekenstein–Hawking entropy formula for certain black holes in string theory.

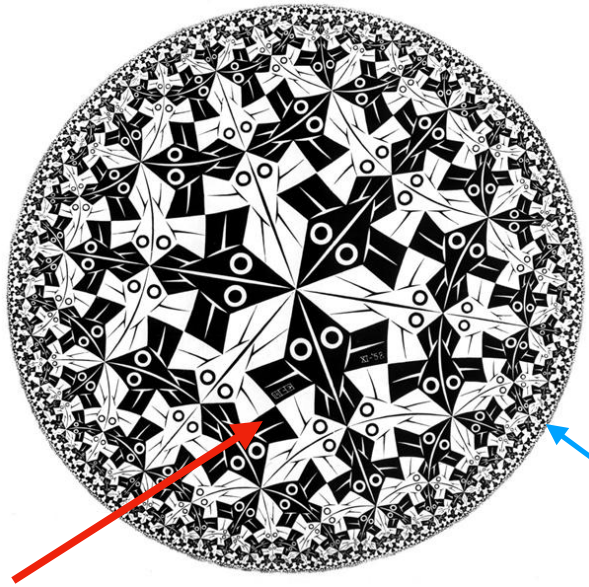
- The microscopic origin of the entropy turned out to be due to a fundamental object in string theory, known as branes (i.e. membranes).
- Branes are extended objects in string theory on which open strings end. They can become dense and massive and become a black hole.



The holographic principle

Another breakthrough in string theory was due to the discovery of the **holographic principle** by Maldacena in 1997.

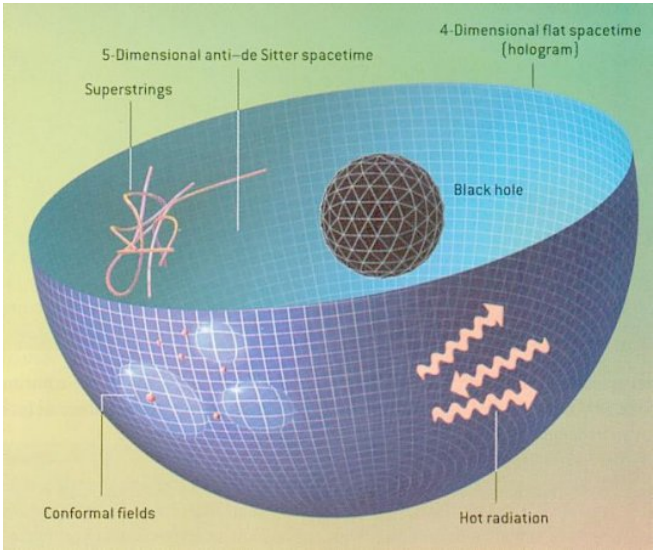
"In the right circumstances, the theory describing elementary particle interactions (quantum field theory), without gravity, is exactly the same as the theory of gravity in higher dimensions."



In the middle of the five dimensional space lives the theory of gravity. It includes black holes, etc.

Quantum field theory (without gravity) lives on the four dimensional boundary. This theory describes high energy particle interactions.

The holographic principle



The theory describing elementary particle interactions (quantum field theory) is a "hologram" of the gravity theory in higher dimensions.

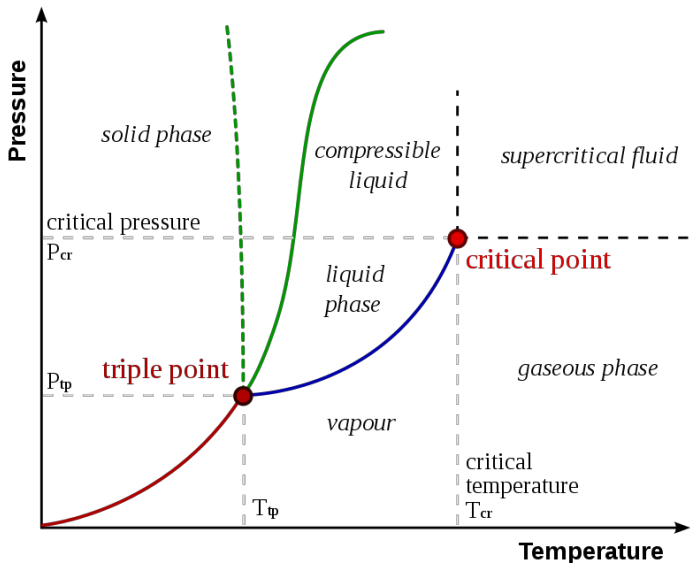
Research of the string theory group.

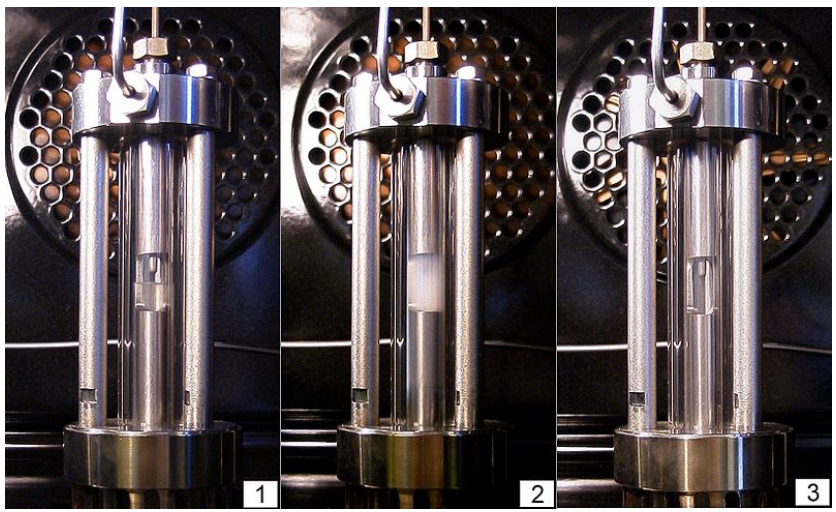
- Give an explanation for the black hole entropy from the perspective of quantum field theory using the holographic principle.
- Understand behaviours of particle interactions from the perspective of the gravity theory.
- Classifying certain classes of quantum field theory using the gravity theory.

String theory and quantum field theory

Quantum field theory can describe a wide range of physical phenomena, not just for high energy particles.

- **Critical point.** The end point of the pressure-temp curve under which a liquid and its vapour can coexist.

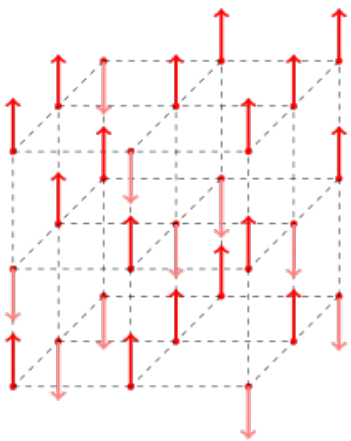




- **Ethane.** (1) Liquid and gas phase coexist; subcritical. (2) Critical point (32.17 °C, 48.72 atm). (3) Supercritical fluid. [Credit: S. Horstmann '00]
- **Water.** The critical point occurs at around 374 °C and 218 atm.

String theory and quantum field theory

- The behaviour of water (and other liquids) at the critical point is described by a type of quantum field theory, known as conformal field theory.
- Consider another physical system consisting of a lattice of spins, each interacts with only the next-door-neighbours. This is known as the three dimensional (3d) Ising model.



Surprisingly, exactly the same conformal field theory that describes water at the critical point also describes the 3d Ising model at long distances.

- Two systems with completely different descriptions (water and a lattice of spins) are described by the **same physics** at long distances.

String theory and quantum field theory

- This phenomenon is known as **duality**. In particular, the critical point of water is *dual* to the 3d Ising model.
- In fact, the holographic principle is also a form of **duality** between the theory of particle interactions and the theory of gravity in higher dimensions.
- String theory gives a number of systems that are related to each other by **duality**.
  - Sometimes, certain systems are easier to be studied than the others.
  - One can then investigate the easy systems, and use their properties to learn about more difficult systems.

Members of the string theory group

Permanent members

Noppadol Mekareeya	Sara Pasquetti	Silvia Penati
Alessandro Tomasiello	Alberto Zaffaroni	

Postdoctoral researchers

Francesco Aprile	Vladimir Bashmakov	Kate Eckerle
Chiung Hwang	Andrea Mauri	Daniël Prins
Valentin Reys	Yegor Zenkevich	

10 PhD students

A brief CV of the speaker

Noppadol Mekareeya

- **Education.**
  - 2007-2011: PhD in Theoretical Physics (Imperial College London)
  - 2004-2007: Bachelor's Degree (University of Cambridge)
- **Experience.**
  - 2017-Present: Researcher, INFN
  - 2016-2017: Postdoctoral researcher, University of Milano–Bicocca
  - 2013-2016: Fellow, CERN
  - 2011-2013: Postdoctoral researcher, the Max Planck Institute for Physics (Munich)