Black holes in string theory

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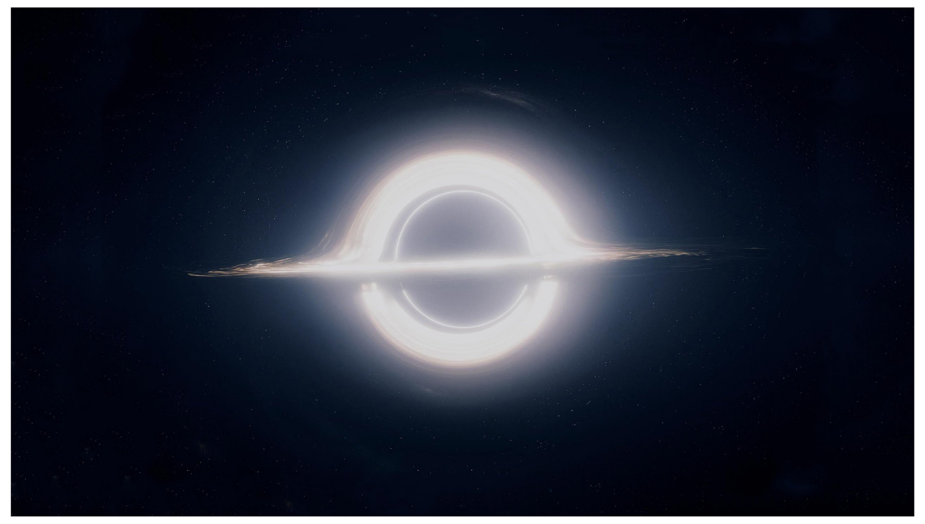
1. The four fundamental forces

All phenomena in nature can be explained with four forces: electromagnetism, which deals with electricity and magnets, the strong and weak nuclear forces, which are only noticeable at the microscopic level and the gravitational force, which deals with gravity. There is a theory which explains three out of the four fundamental forces at the microscopic (quantum) level, which is called the Standard Model. However, it is not able to explain gravity. For that, a separate theory is used: General Relativity. It is, however, a non-quantum theory.

Electromagnetism	**Strong nuclear**	**Weak nuclear**	**Gravitational**
Standard Model Quantum physics			General Relativity Classical physics

2. Black holes in General Relativity

The theory of General Relativity predicts the existence of black holes, which are regions in spacetime where nothing (not even light!) can escape. The picture below illustrates how light and matter are pulled towards the edge of the black hole. There is a point of no return, called the event horizon, beyond which it is inevitable that everything is pulled inside – it can be described as the top of a waterfall!



Source: Interstellar (2014)

3. The black hole information paradox

The Standard Model mentioned above describes very well particle physics, so it is strongly believed that our world is quantum. However, when black holes and quantum effects combine a paradox occurs: black holes violate the quantum laws!

4. Quantum Gravity: String Theory

The paradox emerges because General Relativity is not a quantum theory. In order to understand the paradox, a theory of Quantum Gravity is needed. The main candidate is String Theory. It says that all elementary particles (for example electrons or quarks) are tiny strings which are vibrating, as shown in the picture below. If successful, String Theory will explain all four fundamental forces at the quantum level.

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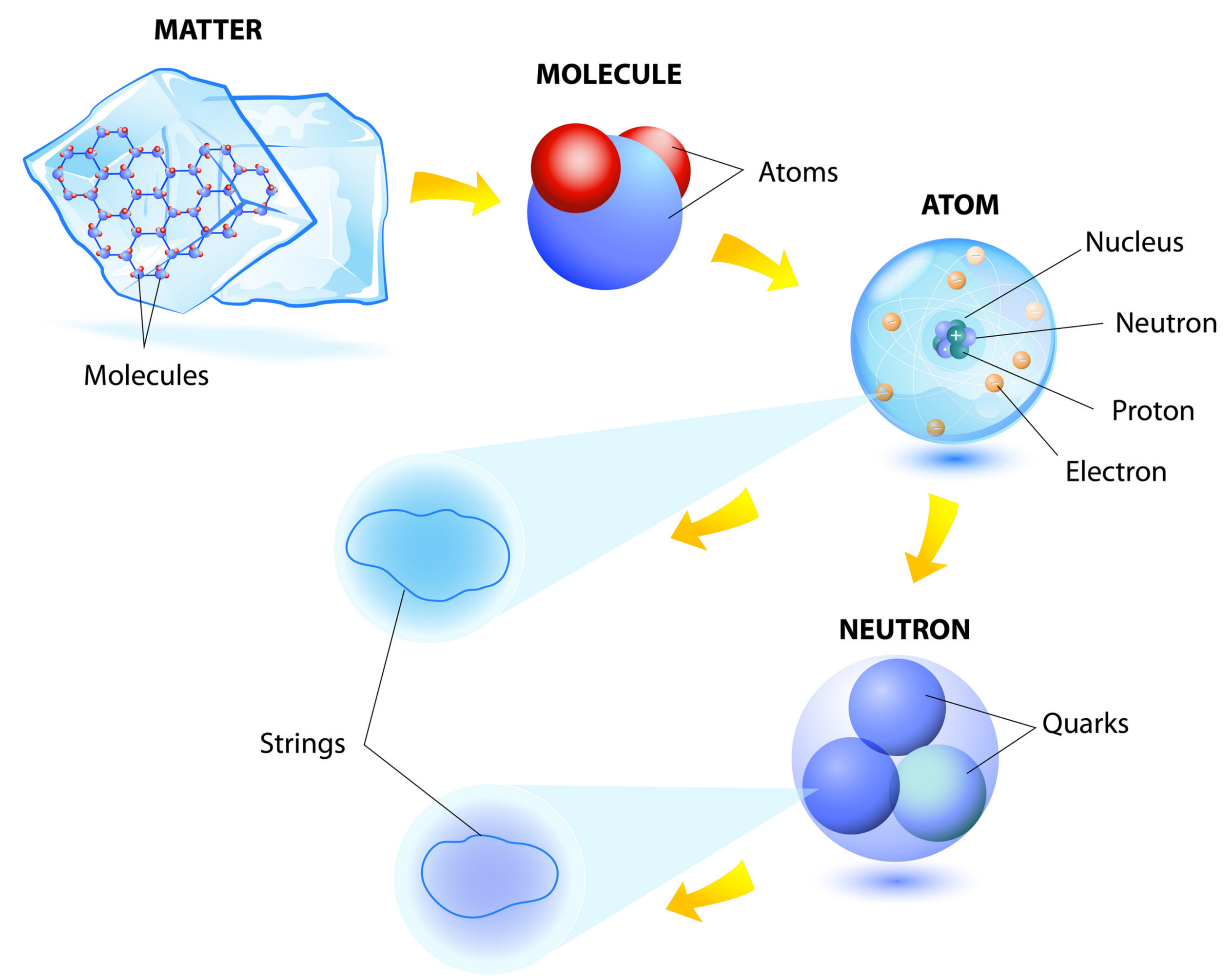
Standard Model Quantum physics			General Relativity Classical physics
String Theory Quantum physics			



Source: Kidspressmagazine

5. The Universe as a hologram

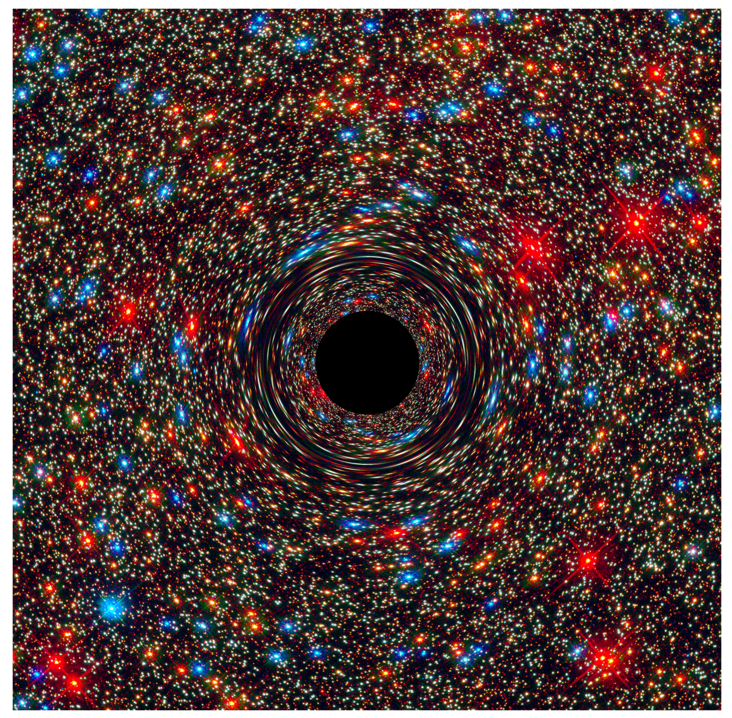
Recently, a new idea has emerged within String Theory: the holographic principle. According to it, a theory of gravity may be mathematically equivalent to another theory without gravity in one dimension less. Results can then be translated from one theory to the other, using the holographic dictionary. This is very useful, as problems which are very hard to solve can be translated to easier problems in another theory, solved there and then translated back!

6. Black holes in String Theory: fuzzballs

When the previous ideas are combined, one may realise that General Relativity may not explain correctly the black hole interior. The fuzzball proposal, which may be string theory's answer to black holes, says that there is no event horizon and that the black hole interior has to be described using String Theory. With this the information paradox can be avoided!

7. My research

The focus of my research is on fuzzballs. Using the holographic principle I am studying the structure of the interior of black holes mathematically (that is, calculations with pen and paper), using a theory without gravity in two dimensions. Black holes still look like black objects from afar, as the simulation below shows for a black hole at the core of a galaxy. The microscopic description does not change that.



Source: Nasa

8. Conclusions and outlook

Black holes are essential for understanding the Universe, but they may not be as we thought. The description that General Relativity gives is not complete, as the information paradox shows. So, a more general, quantum theory is needed. Using String Theory and the holographic principle I am working on the so-called fuzzball proposal, which aims to explain the interior of black holes as a fuzz of strings.
String Theory and the fuzzball proposal are still work in progress though – there are a lot of things yet to be understood!

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