# Quantum gravity in the sky

*Connecting fundamental theory to observations of black holes*

In my research, I try to unravel the structure of space and time at the most fundamental level. With my group, we try to shed a new light on long-standing gaps in our knowledge of spacetime using a combination of theoretical developments and insights from cosmology and the latest astrophysical observations of black holes.

Black holes are key predictions of Einstein's theory of General Relativity that describe the densest forms of matter known to man, with extreme effects on space and time in their vicinity. Their existence have been confirmed by myriad astrophysical observations, from the supermassive black hole in the center of our own Galaxy, to the much smaller merging black holes discovered recently with gravitational wave experiments. The peculiar properties of black holes, such as the event horizon marking a region from which no escape seems possible, have sparked the imagination of many. Not only do black holes play main roles in popular culture, see the movies Event Horizon (1997), Star Trek (2009) or Interstellar (2014) to name but a few, they have also continuously mesmerized a wide scientific community since their first appearance in theoretical physic literature many decades ago.

Recent scientific discoveries have put black holes at the heart of scientific attention once again.  In the last decade, theoretical research in quantum gravity at the interface of Einstein's General Relativity and Quantum Field Theory, the physics of the smallest, on the other indicated that the event horizon might not be the one-way window we take it for. Outside observers might actually learn about the insides of black holes after all! Not only would that solve long-standing theoretical issues, such as Hawking's information paradox, but it would also lead to potentially observational effects that could shake the very foundations of our understanding of the universe.

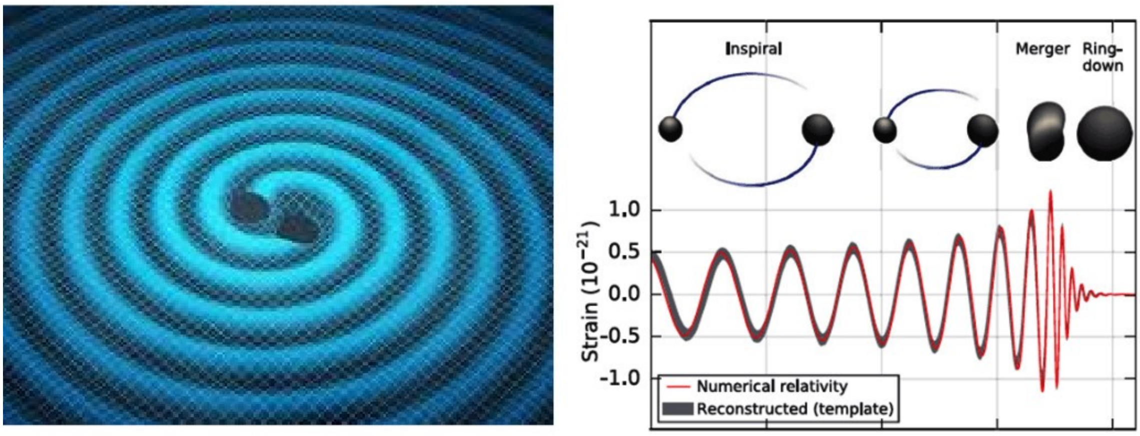


*Figure 1: Left: A binary black hole emitting gravitational waves (Image Credit: Swinburne Astronomy Productions). Right: Gravitational waveform detected from the first confirmed binary black hole merger in 2015. (Image Credit: LIGO/Virgo collaboration).*

Those developments come at a time when new observations are precisely probing the near-horizon region of astrophysical black holes (Figure 1). The Event Horizon Telescope combines various telescopes in the electromagnetic spectrum to image the immediate surroundings of supermassive black holes in our own galaxy and beyond. Gravitational Wave experiments allow us to "hear" the ripples of spacetime produced by dramatic effects as the merger of two black holes to a final, larger, black hole. All of this comes on top of a host of other experiments, such as X-ray observations of stellar mass black holes.

This is a tremendous opportunity: by connecting quantum gravity to observations, we can guide new experiments to potentially huge discoveries and we can use new observations as input for the theoretical framework. However, the tools to make this connection are not fully developed: we lack a complete theory of quantum gravity at the moment. There is currently no consensus in the scientific literature one the size of quantum gravity effects outside black holes as theoretical models differ wildly in their predictions.

My research fits in a wide international effort to build a bridge from fundamental theory to observations and settle those issues. I use string theory, a promising candidate of quantum gravity that also incorporates the other forces of nature (Figure 2). In the past, I looked at formal string theory and its cosmological applications; currently I put focus on the link with black holes because of the scientific urgency.

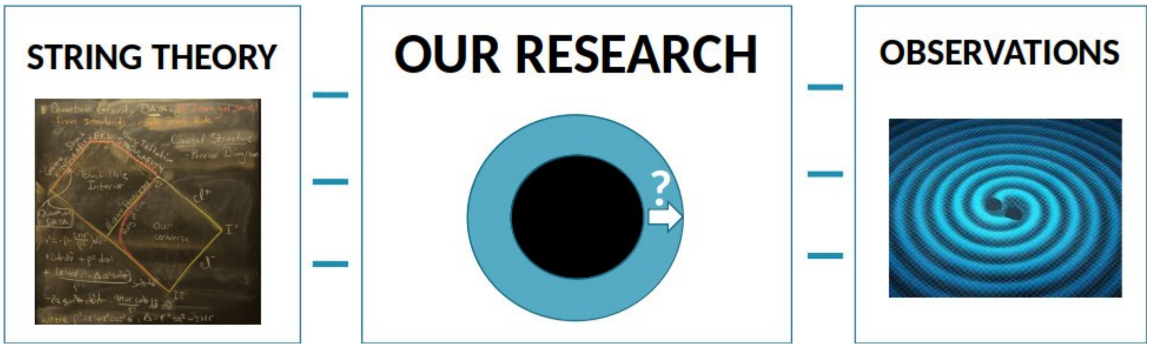


*Figure 2: In our research we explore effects of string theory and quantum gravity on the near-horizon region of black holes (blue). (Left image credit: Dr. Brandt's blackboard on quantum gravity from "Interstellar" by Christopher Nolan. Right image credit: Swinburne Astronomy Productions)*

To make the link to observations we are developing three main lines of research at the Institute for Theoretical Physics in Leuven:

1. **Black hole theory:** sharpen the theoretical framework of quantum effects near event horizons and derive new models of quantum black holes in string theory. This is an analytic study ('pen and paper').
2. **Black hole evolution:** we study how collapsing matter can form an end state that deviates from the predictions of Einstein's General Relativity. For this we mainly use numerical methods to solve coupled differential equations.
3. **Observational effects:** we investigate potential observable consequences of our models. To that end we use a host of numerical computing methods and collaborate with members of the the Event Horizon Telescope and the LIGO-Virgo gravitational wave collaboration.

Just as the study of the atom around 100 years ago reshaped our understanding of matter in terms of quantum mechanics, the study of black holes might lead to a fundamental new understanding of spacetime in terms of quantum gravity.