The Gravitational Memory Effect and Holography

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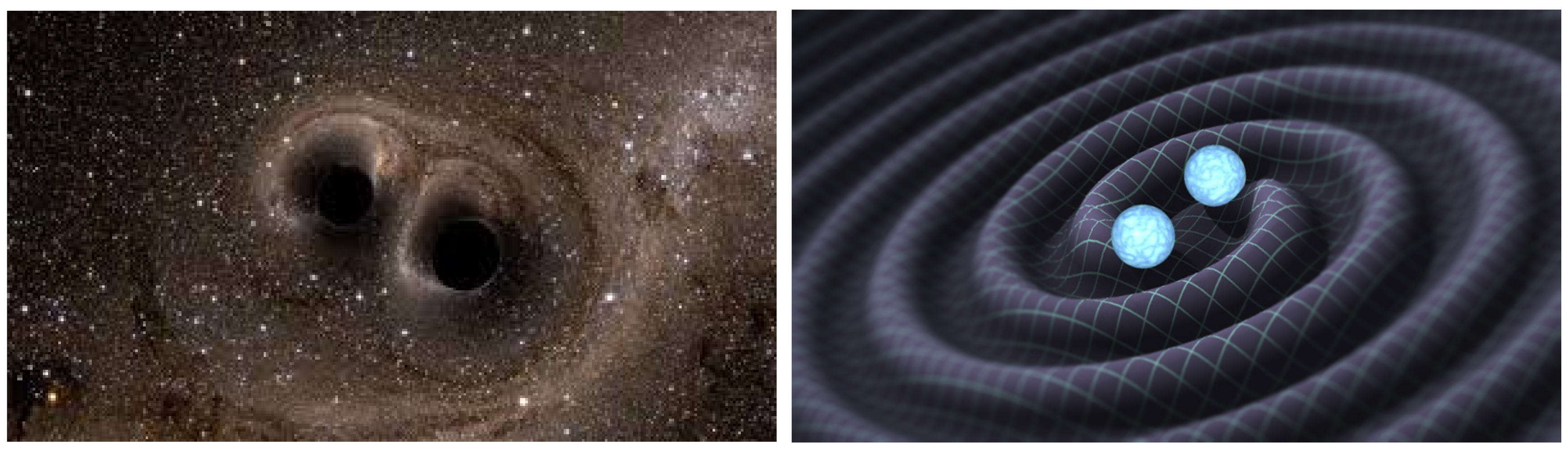
1. Gravitational Waves

In September 2015, the *Laser Interferometer Gravitational-Wave Observatory* (LIGO) first detected gravitational waves: ripples in space time caused by the collision of two black holes over 1,000,000,000 light years away!
LIGO has since detected signals corresponding to 3 more black hole mergers and in August 2017 they detected gravitational waves corresponding to a different astrophysical event: The collision of two neutron stars.



(a) Black Holes Colliding (b) Neutron Stars Inspiralling

Figure: Artistic Impressions of Gravitational Wave Sources [*Source: LIGO*]

These detections not only confirmed a key prediction of Einstein's theory of general relativity, but have opened up a new window of gravitational wave astronomy. As theorists we want to ask what we will see next!

2. The Memory Effect

A prediction of gravitational waves that we are yet to measure is the so-called gravitational memory effect. The set-up is the following:

- Imagine we have two particles at a fixed separation l
- Subject these particles to a burst of gravitational waves
- The waves will force the particles to oscillate and eventually settle down after the waves have passed
- Theory predicts the particles will now have a different separation $(l + \Delta l)$ after the waves have passed. The particles *remember* the passing of the gravitational waves!

3. Testing the Memory Effect- LIGO/VIRGO

Two candidates for detecting the memory effect are the Earth-based detectors LIGO and VIRGO.
LIGO's setup is that of two separate interferometers in the USA; one in Washington and one in Louisiana. Recently the VIRGO detector in Pisa, Italy has also come online. Gravitational waves from both black holes and neutron stars have been observed.

Figure: LIGO's Hanford detector [*source: LIGO, Caltech, MIT, NSF*]

As of yet, LIGO/VIRGO have yet to detect any evidence of the memory effect. In the coming year LIGO will cease observations to work on the precision of their detectors, allowing them to observe farther out into the universe and hopefully increase the number of detections!

4. Testing the Memory Effect- LISA

Another possibility are the LISA detectors: These are gravitational wave detectors in orbit on special paths known as geodesics. The system of 3 detectors (shown in the figure) should be able to observe the memory effect

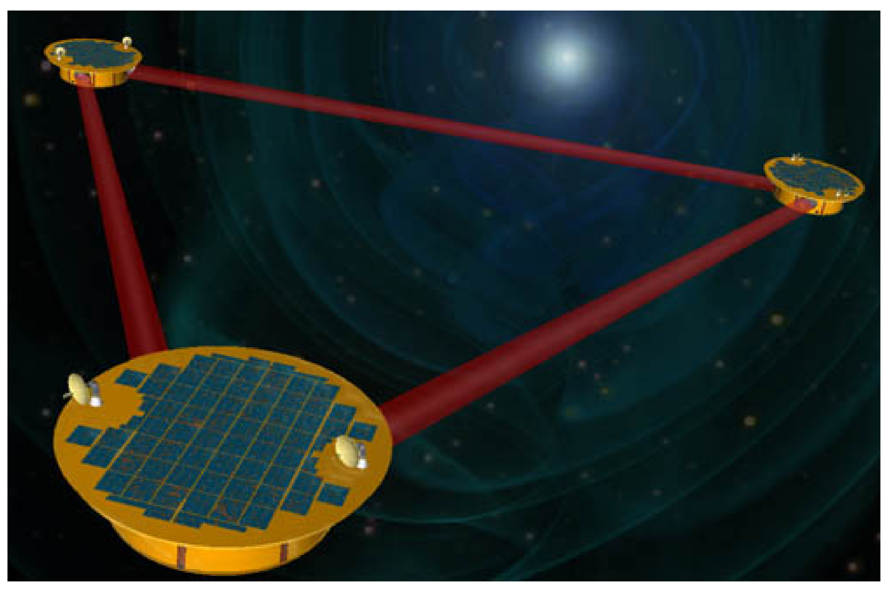


Figure: Artistic Impression of LISA's orbital detectors [*source: LISA*]

One of the hopes for the LISA detectors is that they will be able to detect gravitational waves from super-massive black holes and be sensitive to what is happening at the surface of a black hole; the horizon.

5. Holography

The holographic principle is a physical formulation which attempts to unify the previously incompatible theories of gravity (large scales such as stars and planets) and quantum theory (tiny scales such as electrons and quarks)
The holographic principle states that a theory of gravity in d dimensions is equivalent to a quantum theory in $(d-1)$ dimensions. The quantum theory is a 'hologram' of the gravitational theory.

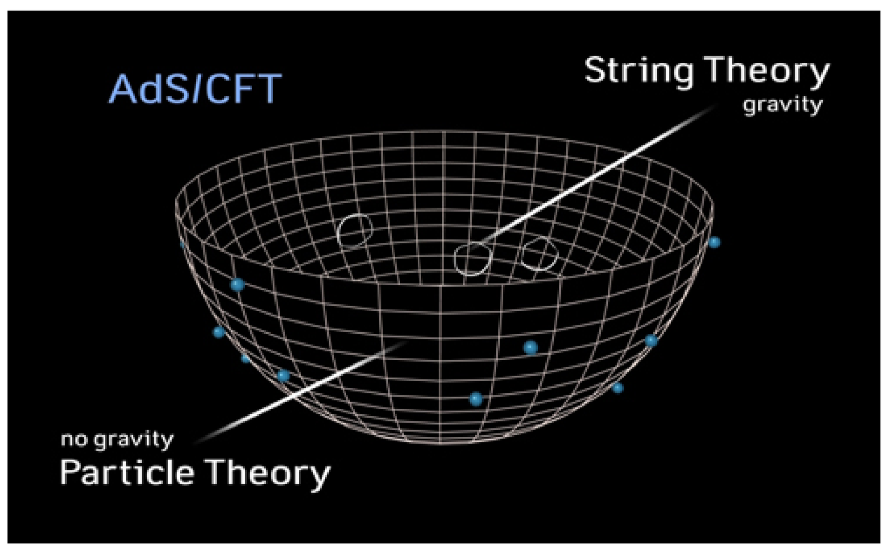


Figure: Schematic Picture of Holography [*Source: Annenberg Learner*]

The best known conjecture of holography is the Anti-de-Sitter/conformal field theory correspondence. This has been studied with great interest in a theoretical context although there has yet to be any experimental confirmation.
Holographic theories suggest deviations from Einstein's theory at black hole surfaces, that may be observable with LISA.

6. My Research

As a PhD student in the Department of Mathematical Sciences. I am interested in studying gravitational geometries known as Bondi-Sachs space-times. These gravitational set-ups play an important role in the mathematics of the memory effect as the symmetries of these space-times are related by different types of gravitational memory.
I also look at the holographic understanding of such space-times which is done by studying these geometries with Anti-de-Sitter asymptotics. From this work we will hope to be able to understand both the quantum theory related to gravity as well as an understanding of holographic theories with different asymptotics.

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