Optimizing the Detection of Hawking Radiation in anti-de Sitter Space

Brown University Undergraduate Teaching and Research Award Presentation
Presented by Jahmour Givans under the advisorship of Prof. David Lowe
August 7, 2015

Measurement and Decoherence

In quantum mechanics, systems are described by wavefunctions made up of sums (linear combinations) of all possible states of the system. When a measurement is performed on a microscopic system that system "collapses" into a single state. This has been extensively verified microscopically, but we do not experience this with macroscopic objects. One phrasing of the measurement problem of quantum mechanics is, "How does wavefunction collapse occur and how do we go from a quantum reality of many states to a classical reality of a single state?"

Decoherence refers to situations in which a system (for example, an electron) spontaneously interacts with its environment (say, stray cosmic particles), leading to suppression of interference effects. You may ask, "How does this suppression occur?" The answer is that during the interaction, the electron becomes entangled to the cosmic particles. Interference can only be noticed in an experiment with the new larger system of electron and particles. So if the electron alone were measured the results would be as though the electron already "collapsed" onto a particular state, since phase relations that lead to interference are now distributed over the larger system. [1]

Quantum field theory (QFT)

QFT is a physical theory that posits the existence of a field that permeates all regions of space. Excitations of this field give rise to the creation of particles, which propagate as waves and are continually being created by and reabsorbed into the quantum field.

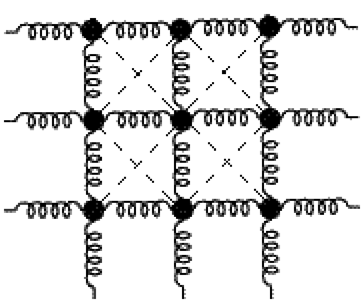

Figure 1. A mass-spring lattice representing the quantum field.

Black holes

A black hole is a region of spacetime bounded by an event horizon in which the gravity is so strong that nothing—not even light—can escape it. Black holes are characterized by three quantities: mass, angular momentum, and charge. My research involves black holes with mass but zero angular momentum and zero charge, so-called Schwarzschild black holes.

Fig 2. A black hole used in the Warner Brothers movie *Interstellar* (2014).

Hawking radiation

Hawking radiation is a mechanism through which black holes give off energy and "evaporate away" over time. One formalism of Hawking radiation involves considering a particle-antiparticle pair forming just outside the event horizon, with the negative energy particle falling into the black hole and the positive energy particle escaping away. The former removes energy from the black hole, lowering its mass in the process, while the latter may be detected by an observer as a quantum of Hawking radiation.

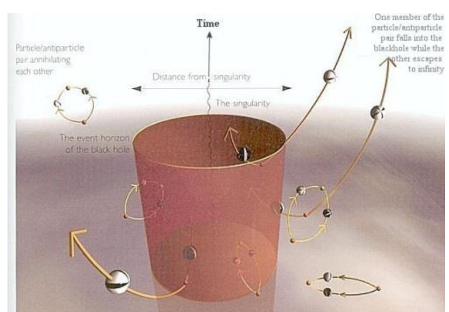

Fig 3. Conical view of a black hole and its Hawking radiation.

Scrambling

Scrambling is a form of thermalization (systems reaching thermal equilibrium through mutual interactions) that applies to the evolution of closed systems. As time progresses it becomes impossible to determine the initial state of the system without measuring a particular fraction of all the system's degrees of freedom. We call the minimum time it takes for information about the original state to be lost the scrambling time of a system. [2]

My project

My task is to determine the efficiency of detection of Hawking radiation as a function of the detector's distance from a black hole. Efficiency, in this case, refers to the probability of detection of a Hawking particle. To do this I'll need to solve for mode functions, calculate the average particle flux, and determine the blueshift factor for the modes. Our conjecture is that at the distance corresponding to maximum efficiency, the minimum decoherence time equals the scrambling time. We also predict that the time it takes for the infalling particle to reach the singularity is faster than the scrambling time. We will attempt to support the work by Sekino and Susskind which argues that the scrambling time is on the order of the inverse Hawking temperature times the logarithm of entropy. This counters the conjecture of UCSB which argues this time can be arbitrarily fast; if that were the case then problems arise which may necessitate the existence of a firewall.

References

[1] Bacciagaluppi, Guido, "The Role of Decoherence in Quantum Mechanics", *The Stanford Encyclopedia of Philosophy* (Winter 2012 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/win2012/entries/qm-decoherence/>.
[2] DOI:10.1007/JHEP04(2013)022
Figure 1: From the coursework of George Karakonstantakis for Physics 372 at Stanford University. Uploaded March 20, 2008.
Figure 2: D. L. Cade, Recreating the Incredibly Accurate CGI Black Hole in Interstellar with In-Camera Elements. November 4, 2014.
Figure 3: From the Hawking Radiation page on https://universe-review.ca