# Developing analog systems for the interior of blackholes

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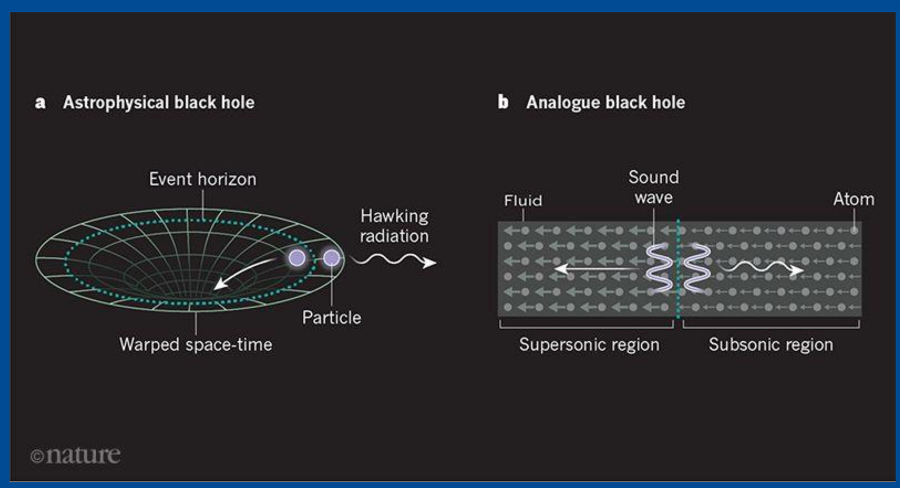
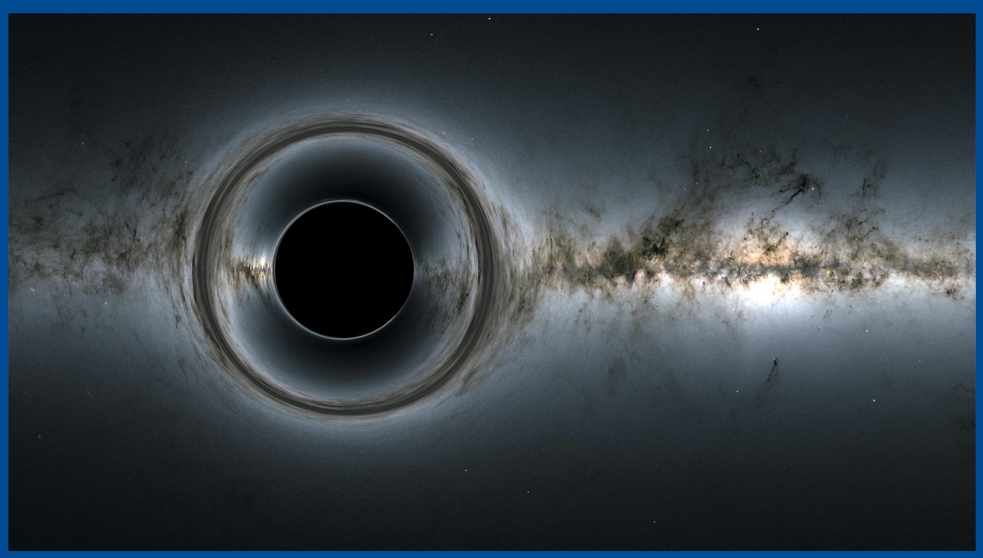
## Introduction:

This study aimed to build a macroscopic analogue of a quantum scale system known as an FSY system, which is thought to be related to the inside of a blackhole. Multiple methods were explored, and a model based on interconnected circuits, with currents representing the important quantities was eventually decided on. This model has been partially worked out, however there is still more work to be done on it.

Blackhole vs Sonic Blackhole




It is impossible for a measurement device to measure the trapped particle and for its information to escape the blackhole, thus a model is necessary for any study of such a system. To do this, various methods have been used, such as through sound: a sound wave travels through a perfect fluid, phonons (vibrations) are produced on this wavefront, one escaping the sound wave, one unable to escape. Other models focus on using light and superconductor circuits to produce very similar systems. My project is to produce an analogue for a system thought to model the inside of a blackhole called an FSY system.



At the frontier of modern physics the energy required to experimentally test much current theory is far beyond our technological capabilities. One way in which physicists try to get around this is producing systems which obey the same mathematical equations, but are on similar scale to the world we live in. The most well-known, successful example of this is the modelling of the edge of blackholes or more precisely their hawking radiation. The production of pairs of particles on the edge of a blackhole. One of these particles escapes, the other is sucked into the blackhole. This is the process through which blackholes decay.

An FSY system is more usefully defined as a pair of Dirac solitons, two electrically neutral particles bound together by mutual strong gravitational attraction, prevented from collapsing by the uncertainty principle. However testing systems like FSY are highly difficult as they are on a far smaller scale than we can hope to probe for the foreseeable future (their size is one the same order of magnitude as the Planck length ~ 1.6*10^-35).

## Failed models:

The first attempt was to have a graphene sheet as space time and the charges as particles. This model is the most immediately intuitive since it is not a big leap to visualise the charges as masses and the graphene sheets' reactionary charge distribution as the curvature of the rubber sheet, like in visualisations of General Relativity (**Figure 1**). However, it was quickly realised that, as graphene is very stiff, it is highly inflexible to manipulate the sheet greatly, so there would be a maximum gradient reasonable, thus it becomes far less useful.

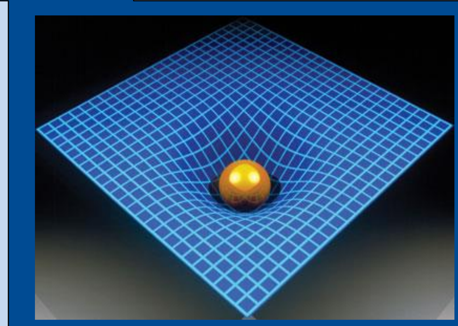


Figure 1

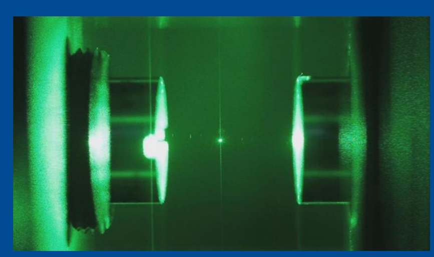


Figure 2

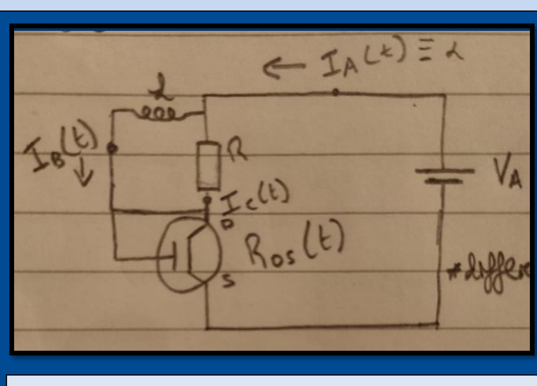
The second method we considered was to use a non-linear optical device to simulate the particles as photons in the cavity (**Figure 2**). Since this is inherently quantum mechanical and an area where there is a large body of research available, it was initially thought to be promising. However since photon-photon interaction doesn't occur, various apparatuses would be required to allow there to be any gravitational analogue, so this model also wasn't explored properly either.

The third method was inspired by a Hawking radiation analogue. The idea was to have two Josephson inductor (superconductor) transmission lines, long lines of a repeating circuit shown in **Figure 3**. This was an interesting possibility as you naturally get the back action required (the equivalent of the particles mass altering spacetime. However it was found that to achieve this system, rearrangement of the equations into second order equations in two variable was required and it was found that the equation found was far too complex to form a useful model.

## Final model:

The model represents each individual equation as a small circuit and connects them in such a way as to eventually form the complete equations. Throughout the rest of the essay, a is the amplitude of the particle which will be called alpha, b is the amplitude of the antiparticle which will be called beta, A is the spatial curvature, T is the temporal curvature, r is the radius, m is the mass (eventually set to 1) and w is a frequency (also eventually set to 1). In our model however we are modelling the radius from FSY to be time, ie. the distance from the center of the FSY system corresponds in our model to the time elapsed from the beginning of the run. The quantities a, b, A and T correspond to the identified current in their corresponding circuits.

Figure 4



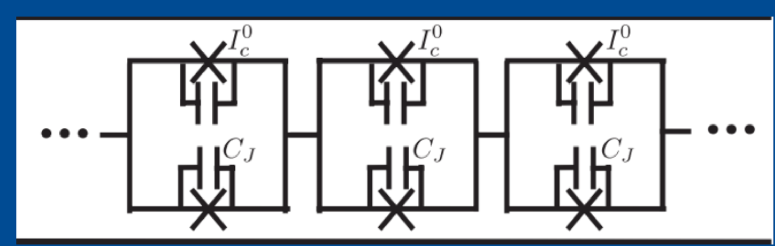
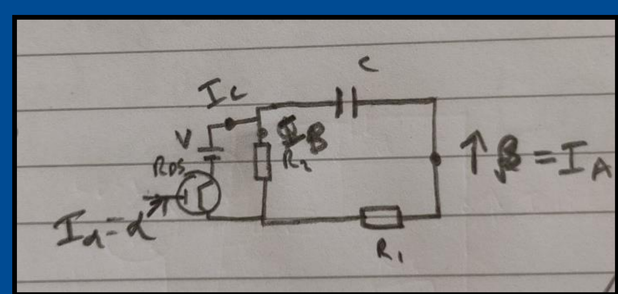


Figure 3

Figure 5



For the first FSY equation: Sqrt[A] a' = a / r - (w T + m) b, we start with the internal equation: a' ∝ a which call for internal gain in the circuit, ie the current increases by a rate proportional to the size of itself. To do this, we started with the transistor set up in **Figure 4**, where we add a transistor in parallel next to a cell, with gate voltage coming from the circuit itself, we find this gives the correct sort of expression. The inductor was added to prevent rapid feedback gain from causing the current to reach maximum current too fast. The negative proportionality with the beta circuit turned out to be a greater challenge, however various possible directions for this have been discussed in the essay, as have the extensions to include T and A dependence.

To make the beta circuit, corresponding to the second FSY equation: Sqrt[A] b' = (w T - m) a - b / r. First, we found the internal circuit which satisfies b' ∝ - b/r by starting with a circuit which exhibits exponential decay, an RC circuit and then introducing the requirement that the capacitance increases with time (as C=t/R). To then add the alpha circuit dependence, we added the transistor in parallel with the setup as shown in **Figure 5.** The dependences on T and A have not yet been accounted for properly (though have been explored in more detail in my essay).

For equation 3: A' = 1/r - A/r - 16 𝝅 w T^2 (a^2+ b^2)/r, start by again achieving A' ∝ - A/r dependency like for Equation 1 with an RC circuit with variable capacitor. To introduce the A' ∝1/r term (decelerating increase of current), we add a cell and variable resistor in parallel with the circuit and vary the resistor according to R1=(V t-R3)/(1+R3/R2) where all variables are labelled in **Figure 6**. Again adding the extra dependencies has not been finalised but has been explored extensively in my essay.

$$\sqrt{A}\,\alpha' = \frac{1}{r}\alpha - (\omega T + m)\beta,$$

$$\sqrt{A}\,\beta' = (\omega T - m)\alpha - \frac{1}{r}\beta,$$

$$rA' = 1 - A - 16\pi\omega T^2(\alpha^2 + \beta^2),$$

$$2rA\frac{T'}{T} = A - 1 - 16\pi\omega T^2(\alpha^2 + \beta^2) + 32\pi\frac{1}{r}T\alpha\beta + 16\pi m T(\alpha^2 - \beta^2).$$

FSY equations in full

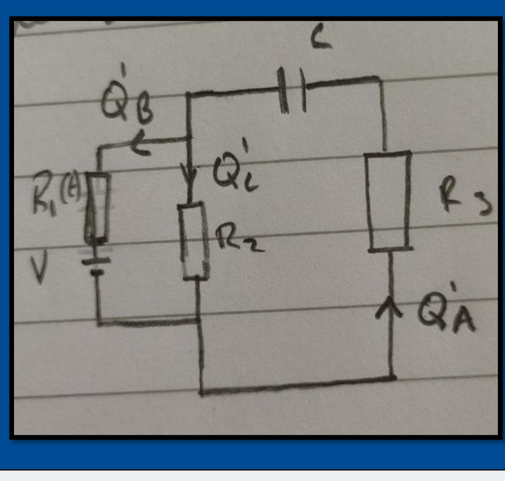


Figure 6

Equation 4 was not dealt with properly, however most of it will follow from very similar methods to the previous three. The main difference will be the cubic dependence on T, though this can either be approximated by choosing the correct region of a non-linear capacitor or by a more precise approach.

References:
Blackhole picture - https://www.nasa.gov/vision/universe/starsgalaxies/black_hole_description.html
Second, sonic blackholes DOI: *Nature*, 2019. 10.1038/s41586-019-1241-0
Figure 1- https://physics.stackexchange.com/questions/155547/visualizing-gr-spacetime-distortion-in-11d-spacetime-instead-of-2d-space
Figure 2-Credit: James Millen (UCL Physics & Astronomy)- https://www.flickr.com/photos/uclmaps/16841346482/
Figure 3- https://arxiv.org/abs/0904.2589

I would like to thank my supervisor, Dr Chris Hooley, for the opportunity to work with him and explore this fascinating area of physics. I would also like to thank the entire Laidlaw team, especially Lord Laidlaw himself, who made the Laidlaw Scholarship program possible.

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