Black to White Hole Tunneling

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Introduction

The dynamics of gravity is full of intriguing instabilities. Universal attraction causes a nearly smooth collection of matter containing only small variations in density to dramatically clump and results in the richly varying galactic landscape we see around us. This is the origin of structure in the universe.

Great clouds of accumulated dust formed in this landscape are the nurseries for stars. As a star ages and burns through its fuel, a second gravitational instability takes hold. If the star is massive enough, the gravitational pull of the matter overcomes all of the star's internal pressures and the star collapses. A black hole is born.

Remarkably, black holes, so famous for capturing light, are also unstable and do not live forever. However, the details of how long they do live and what eventually becomes of them are shrouded in mystery. What happens to the matter that collapses to form a black hole? Do they really outlive everything else in the universe? Here we suggest that quantum mechanics could play a dramatic role in the fate of a black hole, allowing it to transform into its symmetric opposite, a white hole, and explosively throw out its contents.

What is Gravity? A Black Hole?

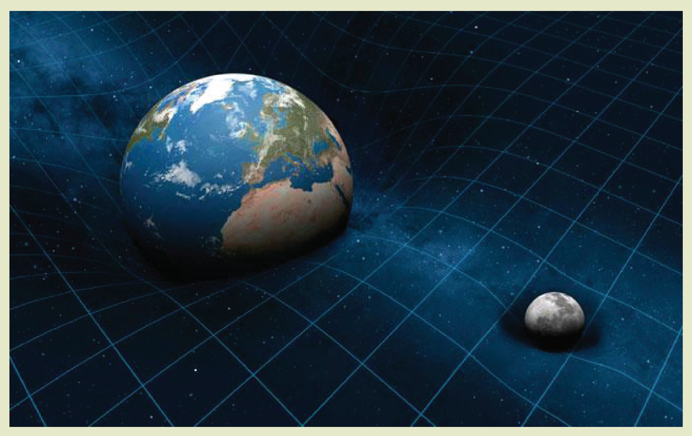
Upon inventing his astonishing theory of gravity, as the attractive force between two massive bodies

$$F = \frac{GmM}{r^2},$$

Isaac Newton had this to say about it:

> *That one body may act upon another at a distance through a vacuum without the mediation of anything else, by and through which their action and force may be conveyed from one another, is to me so great an absurdity that, I believe, no man who has in philosophic matters a competent faculty of thinking could ever fall into it.*

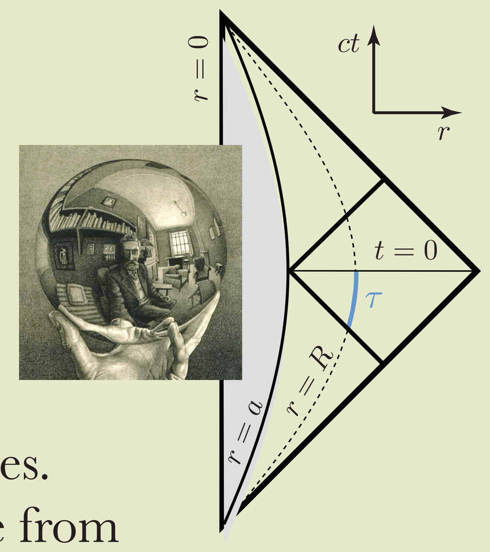
It was in response to this concern that Einstein reformulated gravity as the bending of space and time.



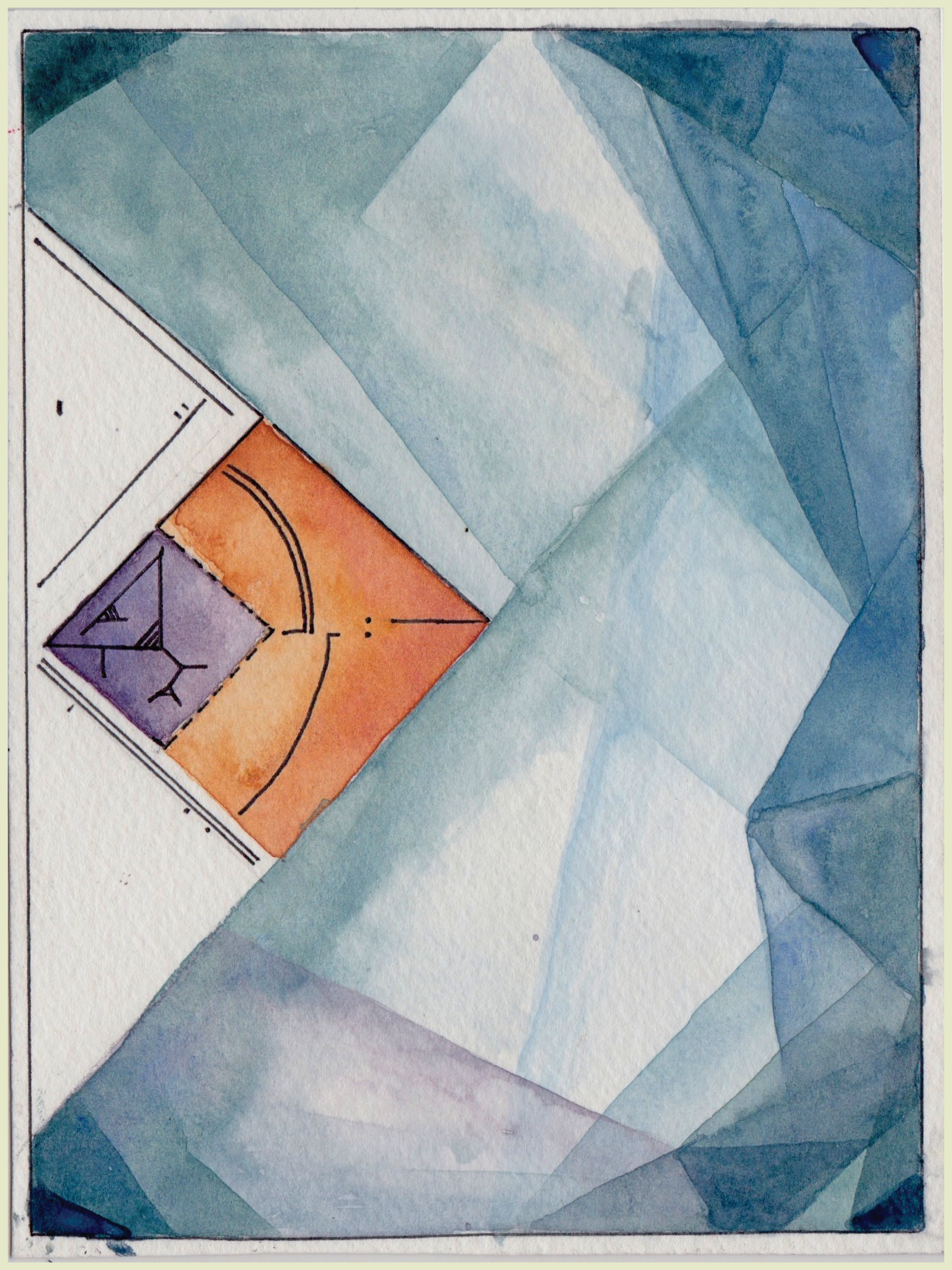
A black hole is a locale in space and extent of time where this curvature is so extreme that nothing, not even light, can escape. A clock near any mass will click more slowly than one further from that mass. This effect becomes quite strong near a black hole and the difference in the flows of time can be extreme.

Picturing Space and Time

Because gravity involves the bending of both space and time, it is quite useful to picture both of these facets of Nature together. We draw a diagram where time flows upwards and space extends along the horizontal. Wonderfully, in this diagram light travels along the 45 degree diagonal lines. The time it takes light to bounce from a crystal ball of radius a depends on its mass M and is



$$\tau = \sqrt{1 - \frac{2M}{R}}\left(R - a - 2M \ln \frac{a - 2M}{R - 2M}\right).$$



Artwork by Kaća Bradonjić

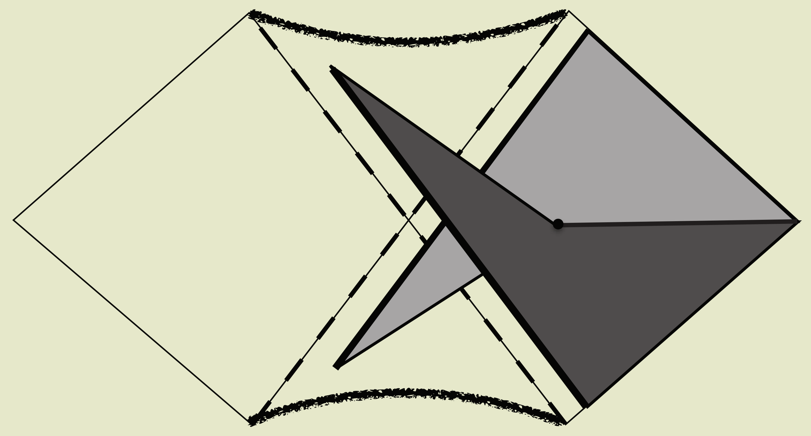
Quantum Gravity

Quantum mechanics is a deep patterning that underlies all of Nature. Despite this, the relations between causes and effects that we experience daily are quite different from those when quantum mechanics is at play. For example, microscopic particles can tunnel out of confines that everyday expections would say they should not. This behavior would be like a ball traveling through the wall of your living room without breaking it.

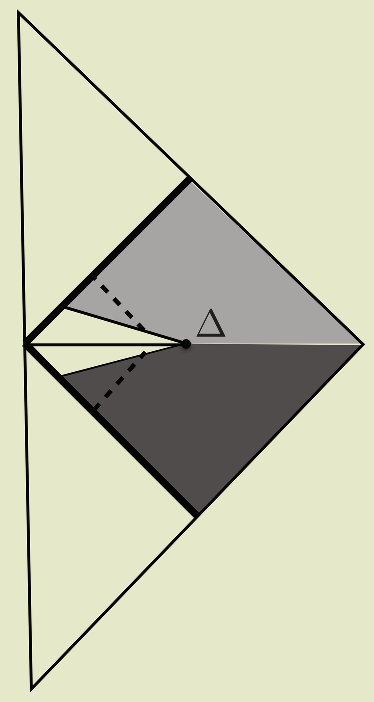
But, if space and time are physical, maleable entities, can they too behave in this quantum fashion? If so, is it possible that, given enough time, a black hole could tunnel into a symmetrically opposite geometry and become a white hole?

Black to White Hole Tunneling

Investigating this question, we wondered whether we could build a new solution to Einstein's equations where collapsing matter bounces back out. This would be a geometry where a black hole in the past was glued to a white hole in the future. There is a solution with a black and a white hole combined, but it is mixed up with a white hole in the past and black hole to the future:



Performing the mathematical equivalent of a cut and paste operation we divided this spacetime geometry up into the two grey regions pictured above and untwisted them [1]. The result was a spacetime with a black hole in the past, a white hole in the future, and a thin quantum region in between:



This quantum bounce of a black hole into a white hole changes the expected life span of a black hole, which could now scale with the square of the black hole mass M [2]:

$$\tau_q \sim M^2.$$

This means that we may be able to observe the end of a black hole.

Observations?

A speculative, but intriguing possibility is that we already have [3]. The suggestion is that the recently observed fast radio bursts, whose origins are not understood, could be electromagnetic disturbances created by the explosion of a black hole. There is a clear road to checking this proposal—a wavelength for the burst that increases with red shift slowly is a clear prediction of the scenario.

Conclusion

For some time physicists have believed that black holes will live much longer than the current age of the universe. That quantum mechanics might so radically shift this picture, and that we may be able to obersve the full life cycle of a black hole is a wonderful possibility.

[1] H.M. Haggard & C. Rovelli, PRD **92**, (104020) 2015,
[2] H. M. Haggard & C. Rovelli, IJMPD **25** (1644021) 2016,
[3] A. Barrau, B. Bolliet, F. Vidotto, & C. Weimer, JCAP02 **022**, (1) 2016.

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