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EDITORIAL

Focus on classical and quantum analogues for gravitational phenomena and related effects

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Abstract. Hawking's prediction that black holes are not black but radiate has been one of the intellectually most influential results of theoretical physics, but Hawking's theory has not so far been testable. Recent developments in analogue models of gravity might change that. This focus issue assembles a series of papers that report on steps towards this goal and related physical effects in a variety of physical systems.

Hawking's prediction of radiating black holes [1] gives a tantalizing glimpse of how three seemingly separate areas of physics could be connected—quantum mechanics, general relativity and thermodynamics. It has been used as a test case for potential quantum theories of gravity; they ought to be consistent with Hawking radiation. Hawking radiation is supposed to be created from the quantum fluctuations of the vacuum near the event horizon, thus connecting quantum physics with general relativity, and the radiation should be thermal as if the black hole were a black-body radiator with a temperature dependent on the gravity at the horizon. However, putting realistic numbers into Hawking's formula quickly reveals that astrophysical black holes are incredibly cold and so their radiation would be obscured by the cosmic microwave background. The benchmark for some of the most advanced theories seemed condemned to remain itself theoretical. But something very similar to Hawking radiation could be observed

in laboratory analogues. Here, horizons are not created by gravity but by media that behave like gravity. Newton himself once toyed with the idea that gravity could be mediated by some medium, before settling on his Newtonian theory of gravity, where masses perform action at the distance across space. In Einstein's theory of gravity—general relativity—masses act locally, they curve space–time around them, and then the overall effect of curvature appears as gravity. However, returning to Newton's early thoughts, we may interpret many space–time geometries as media. To give an example, an optical medium such as glass appears to modify the spatial geometry seen by light. According to Fermat's principle, light takes the shortest optical path, but with a measure of length set by a varying speed of light in the material, thus curving light rays as in Einstein's general relativity. For instance, the gravitational lensing produced by a galaxy resembles that seen as light goes through the bottom of a wine bottle. Going a step further, moving media change the geometry of space–time, not only the measure of space, and they may create horizons.

Unruh [2] invented a beautiful analogy for the event horizon. Imagine waves in a moving medium, for example, water waves in a river, where the river is the medium for the waves, see, e.g. [15]. Where the river flows faster than the speed of the waves they can no longer propagate upstream and are trapped behind a horizon. The horizon is the point of no return where the counter-propagating waves begin to drift backwards. This analogy works for many other waves—light waves in moving media made by nonlinear optics (see, e.g. [12]), sound waves in Bose–Einstein condensates (see, e.g. [8, 17, 18, 21]) and other fluids (see, e.g. [19]) or in chains of trapped ions (see, e.g. [6, 14]) and so on. Horizons are ubiquitous. The important point is whether such laboratory analogues are able to create the analogue of Hawking radiation.

What can we learn from the analogue of Hawking radiation? First of all, we connect abstract concepts with hands-on physics, theory with experiment. The link between mathematical theory and empirical facts is the great strength of the physical sciences. Without experiments, theories may run wild or wither. Observations of Hawking radiation and related phenomena are important for quantum theories of gravity that are barely testable. They may give insights into the physics behind Hawking radiation and also into the limitations of the present theory. Some unphysical assumptions are made in Hawking's theory. In particular, Hawking radiation seems to originate from the quantum physics at extremely short scales—beyond the Planck scale—which has remained something of a mystery.

Unruh's analogue [2] model makes it easy to understand why Hawking radiation [1] seems to stem from ultrashort-scale physics. Imagine water waves that emerge just in front of the horizon and picture them in a movie running backwards in time. There, the waves creep back to the horizon where the water is getting faster and faster, they seem to freeze and, if nothing else happens, would oscillate at ever shorter wavelengths beyond all scales. This at least would be the situation with our current understanding of gravity. In the analogue of gravity, the river, something would happen, of course—the waves would change their speed with changing wavelength; the horizon would become fuzzy. In analogue models one can study a large variety of trans-Planckian physics (see, e.g. [16]) and see what happens to Hawking radiation (see, e.g. [6, 20]), with possible surprises (see, e.g. [4]).

Apart from Hawking radiation, the analogy between gravity and laboratory physics can be applied in many other ways, see, e.g. [7]. For example, it is also possible to simulate an expanding universe and to model effects such as cosmological particle creation [14] or topological defect production [10, 13]. More generally, the analogy yields inspiration for the as yet unknown theory unifying gravity and quantum mechanics, see, e.g. [3, 5, 9, 11]. It also

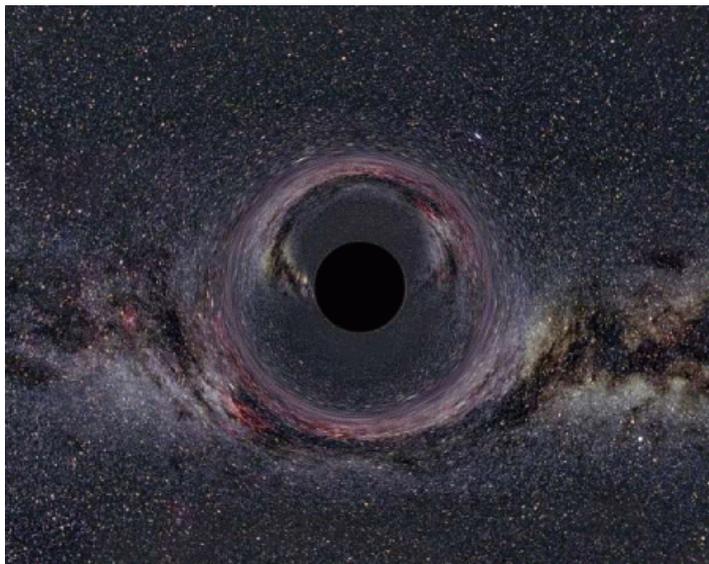


Figure 1. A black hole of ten solar masses, as seen from a distance of 600 km with the Milky Way in the background. Image: Ute Kraus, Physics Education Group (Kraus), Universität Hildesheim, Space Time Travel⁴.

offers important opportunities to actually test these ideas experimentally (at least in principle) by means of analogue models.

This focus issue assembles a series of papers that report on steps towards this goal in a variety of physical systems. We hope that readers get an impression of the breadth and wealth of physics in this research area and aspire to new horizons themselves.

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⁴ www.spacetime-travel.org

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