HAWKING RADIATION

The life of an analogue black hole

Table-top superfluid experiments offer a way of bringing the physics of astrophysical black holes into the lab. But the presence of two event horizons in these superfluid black holes complicates matters — and makes them more interesting.

Giovanni Modugno

In 1975, Stephen Hawking predicted that black holes can slowly evaporate through the emission of electromagnetic radiation[1]. However, Hawking radiation has not yet been observed in astrophysical black holes because the emission scales inversely with mass and is therefore tiny. But William Unruh found a way out when he predicted that event horizons analogous to those in black holes could appear in hydrodynamic systems[2], giving rise to a new field using table-top experiments to probe analogue black holes[3]. Now, writing in *Nature Physics*, Victor Kolobov and colleagues report that they have studied the time evolution of an atomic superfluid black hole featuring two event horizons, and confirmed the stationary nature of spontaneous Hawking radiation[4].

The team simulated the black hole as illustrated in Fig. 1 using a Bose–Einstein condensate of ultracold atoms, trapped in an elongated harmonic potential and accelerated by an optical potential step moving along the condensate. Sound waves or phonons played the role of the photons emitted by astrophysical black holes. Because the sound velocity depends on the density of the condensate, which varies along its length, they were able to distinguish between two regions that mimicked the inside and outside of the superfluid black hole. The inside — where the speed of the condensate exceeded the sound velocity — was separated from the outside by an intermediate point that acted as an event horizon.

The phonons on either side of the horizon corresponded to tiny oscillations of the condensate density, which were hard to detect directly because of the experimental noise. However, they were revealed by measuring the correlation function between the density fluctuations inside and outside the black hole. This allowed Kolobov and colleagues to detect Hawking radiation from the superfluid black hole, which corresponded to the outward-propagating emission at the horizon.

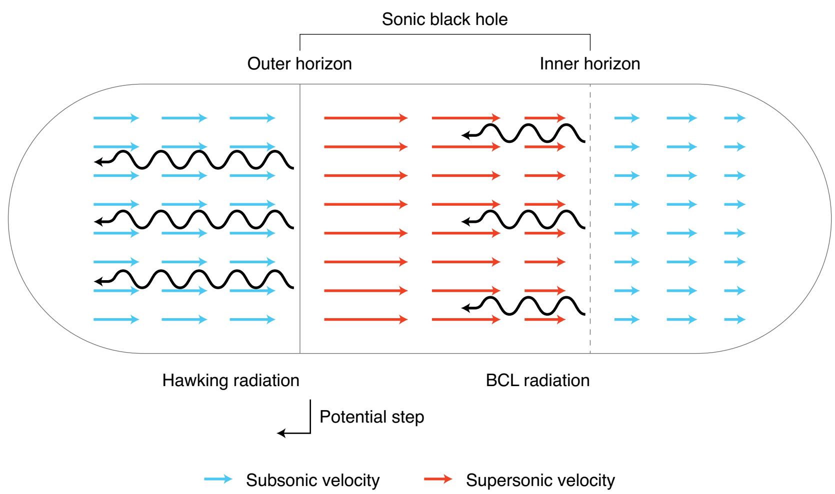

Fig. 1 | Schematic of the sonic black hole. In a Bose–Einstein condensate, a sonic black hole is created. The trapped ultracold atoms are accelerated by a potential step that moves along the condensate leading to the emergence of supersonic (red arrows) and subsonic (blue arrows) regions. These regions are separated by outer and inner horizons at which the emission of sound waves (black curvy arrows) was observed. These sound waves are the analogue of Hawking radiation and Bogoliubov–Cherenkov–Landau (BCL) radiation.

The same group previously observed analogue Hawking radiation[5], and verified not only that it had a thermal distribution but also that the associated temperature was consistent with the prediction from the sonic analogue of Hawking's theory[5]. Since then, they have optimized their experimental setup to better detect correlations. These refinements and the short timescale of less than a second on which the black hole evolves have now allowed them to study its full life cycle.

Kolobov and colleagues detected four different regimes during the lifetime of the black hole. Initially, they observed a slow growth in the intensity of the Hawking radiation, a phenomenon that might be in principle compared to existing models for the growth of astrophysical black holes. This was followed by a stationary period of emission of radiation with a thermal spectrum. The observation is important, because the stationarity reinforces the previous evidence of a thermal spectrum made at a specific time[5] by confirming that the black hole is — at least temporarily — in thermal equilibrium.

Now here is where it gets interesting: the presence of the outer and inner event horizons with opposite properties gave rise to new phenomena characteristic of cavity-like systems, such as black-hole-stimulated emission and lasing. The team found that the strength of the phonons grew rapidly and they stopped being thermally distributed. Instead, they first developed a clear multimode structure followed by a single-mode character.

A similar signal previously reported by Jeff Steinhauer[6] was attributed to black-hole lasing — an oscillation of the Hawking radiation inside the black hole, reminiscent of the behaviour of photons in a laser cavity. Now, with a larger and more precise time-dependent dataset, averaged over many months, this conclusion may need revising. The new measurements show that the sound waves are emitted by the inner horizon, not the outer horizon. This in turn suggests that the phenomenon underlying both multi- and single-mode periods is the so-called Bogoliubov–Cherenkov–Landau emission[7], due to the waves inside the black hole that arrive at the inner horizon with supersonic velocity, in analogy to the sonic waves generated by an airplane moving at supersonic velocities. That stimulates the build-up of a specific oscillation mode, breaking the thermal equilibrium. After some time, the oscillation stopped, because the optical potential step reached the end of the condensate, meaning that the outer space surrounding the black hole vanished.

Although the energy timescales are completely different, superfluid black holes are an increasingly appealing platform for simulating the fundamental phenomena expected in astrophysical black holes. The work by Kolobov and colleagues raises interesting questions that might be addressed in future laboratory experiments. For example, there are already proposals to study pure black-hole lasing in these systems[8], to test the relation between Hawking temperature and black-hole size in analogy with astrophysical black holes[9] and to simulate rotating black holes[10]. ❐

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Competing interests

The author declares no competing interests.