Quantum effects in gravitational collapse and black hole evaporation

Valentina Baccetti[1], Robert B. Mann[2,3], Sebastian Murk[1*] and Daniel R. Terno[1]

[1]Department of Physics and Astronomy, Macquarie University, Sydney NSW 2109, Australia
[2]Department of Physics and Astronomy, University of Waterloo, Waterloo, Ontario, Canada
[3]Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada
[*] sebastian.murk@mq.edu.au

For more than forty years, quantum effects such as Hawking radiation have proven to be a source of inspiration and controversies in black hole physics. They are fundamental ingredients in black hole thermodynamics and are thought to lead to the infamous information loss paradox [1]. In turn, they have motivated many developments of models of compact horizonless objects [2, 3, 4]. To separate essential features from model-dependent properties, I will present some implications [5, 6] that follow from the minimal set of necessary assumptions. The assumptions are that astrophysical black holes exist and their horizon regions are regular. We are working in the framework of semiclassical gravity.

According to a stationary observer at spacelike infinity, the finite-time formation of a trapped spacetime region with regular boundary requires violation of the null energy condition (NEC) [5, 7]. Quantum energy inequalities bound the extent in which such violations are possible. Back-of-the-envelop calculations appear to contradict estimates on the size of negative energy density regions that are obtained on the background of eternal black holes, indicating that the required amount of negative energy density may be incompatible with the standard analysis of black hole evaporation [5].

Contraction of a massive spherically symmetric thin dust shell that separates a flat interior region from a curved exterior is the simplest model of gravitational collapse. Nevertheless, different extensions of this model that include a collapse-triggered radiation lead to contradictory predictions [8, 9]. Analysis of the boundary of a trapped spacetime region identifies two possible families of metrics — ingoing and outgoing Vaidya — that may describe geometry in its vicinity [5]. Description of the exterior geometry using the outgoing Vaidya metric is known to result in horizon avoidance and timelike-to-null transition. We estimate the radial coordinate of this transition. Since violation of the NEC is the prerequisite for a finite-time formation of a trapped region according to a distant observer [5], only the outgoing Vaidya metric with decreasing mass is applicable in this case. Using this metric for the exterior geometry leads to a finite (proper or distant) time of horizon crossing. A macroscopic shell loses only a negligible amount of its rest mass in the process. However, this is incompatible with the NEC violation, thus rendering the horizon formation and its crossing by the shell impossible [6].

1. References

[1] R. B. Mann, *Black Holes: Thermodynamics, Information, and Firewalls* (Springer, New York, 2015).

[2] M. Visser, PoS BHs,GRandStrings 2008:001 (2008), arXiv:0901.4365v3; M. Visser, Phys. Rev. D **90**, 127502 (2014).

[3] C. Barceló, S. Liberati, S. Sonego, M. Visser, JHEP **02**, 003 (2011).

[4] A. Paranjape, T. Padmanabhan, Phys. Rev. D **80**, 044011 (2009).

[5] V. Baccetti, R. B. Mann, S. Murk, D. R. Terno, arXiv:1811.04495 (2018).

[6] V. Baccetti, S. Murk, D. R. Terno, arXiv:1812.07727 (2018).

[7] S. W. Hawking and G. F. R. Ellis, *The Large Scale Structure of Space-Time*, (Cambrdge University Press, 1973).

[8] R. Brout, S. Massar, R. Parentani, P. Spindel, Phys. Rep. **260**, 329 (1995).

[9] A. Ashtekar, M. Bojowald, Class. QuantĠrav. **22**, 3349 (2005).