Dumb Hole Disanalogies[†]

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The following is a list of disanalogies between dumb holes used as analogue models of Hawking radiation for black holes and the black holes themselves, restricted to the level of well known physics (the "regime") in which the analogue experiments are modeled and performed. The list is not meant to be exhaustive. It's just what I've come up with off the cuff while thinking not too long or deeply about the issue. I welcome additions, emendations, corrections, *et al.*

1. Most seriously and egregiously: the excitations in the case of the black hole's Hawking radiation are not of the degrees of freedom encoded directly in the metric (which are spacetime degrees of freedom); in the acoustic black hole, the excitations are of the degrees of freedom encoded in the metric. In other words, in the case of the black hole, there are two systems, spacetime and the quantum field, and the quantum field is excited but spacetime is not (in the quantum field theory on curved spacetime regime, when backreaction is ignored). In the case of the acoustic black hole, there is only one system playing both roles.

2. Some analogue systems are white holes, not black holes (stuff is flowing out of the membrane, and can't get back in, not vice-versa). The issue is that the supersonic potential drop that plays the role of the horizon is moving (say) from right to left in the lab frame, but the condensate is accelerating as it crosses the horizon from left to right, and gets trapped to the right of the horizon. Because black holes never decrease in area, and white holes never increase, stuff *entering* a black hole accelerates in the opposite direction of motion from the horizon, while stuff *leaving* a white hole also accelerates in the opposite direction as the horizon is moving. So one cannot tell from that fact alone whether such models are effectively a white hole or a black hole. The issue must be decided by whether or not small patches of area on the horizon would be increasing or decreasing in size in the future time-direction if the system were not stationary.

3. The modes exiting white holes are negative energy modes, just as are the ones entering the black hole, and the modes in analogue models are obviously all positive, so that is always a serious disanalogy, whether we decide the analogue model is a white hole or a black hole—it seems *prima facie* doubtful that positive energy stuff in fluid has the same backreaction as negative mass stuff in a gravitational field.

4. For BECs, at least, the phenomenon works only at very low temperature, whereas Hawking radiation is supposed to occur over an extremely broad range of temperatures—it would be interesting to check whether this is also true for other analogue systems, *viz.*, whether the temperature ranges in which the experiments will work are severely limited. I suspect they are limited for essentially all studied analogue models.

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5. The radiation for analogue systems is thermalized *at* the horizon, whereas Hawking radiation is thermalized *away* from the horizon (roughly speaking, outside the momentum barrier); correlatively, black holes have a momentum barrier, so the radiation inside the photon sphere is chaotic, but analogue models have no such thing.

6. The effective "Schwarzschild metric" used for the analogues is actually already an approximation to the real Schwarzschild metric, as there is no "reduced part" that is a spherically symmetric metric on a 2-sphere; rather the effective metric is what you get when you look at a "small patch" of Schwarzschild, that is effectively flat except in radial directions. Also, even this holds only under the assumption that the speed of sound is constant in the fluid.

7. Moreover, the acoustic metric is only conformal to the approximate Schwarzschild metric.

8. An event horizon is a true one-way membrane for *all* physical phenomena/processes. Even in the long-wavelength regime, however, it is known, both theoretically and experimentally, that high-frequency modes sometimes will travel back through the acoustic horizon, so even in the relevant regime the acoustic horizon is not truly a 1-way membrane even when consideration is restricted to the particular phenomenon/process at issue, putting aside the issue of the "1-way permeability" of the membrane for *all* physical phenomena/processes. (This was actually a point emphasized to me by Unruh in conversation, so he is of course aware of these kinds of disanalogy, I'm sure, they're just not things I've seen discussed in the literature).

9. The event horizon of a real black hole travels *at* the limiting velocity (technically it's a null hypersurface, so one can think of it as "traveling at the speed of light"); the analogue horizon is traveling *faster* than the *limiting* velocity, *viz.*, supersonically.

10. See "Particle Production in the Interiors of Acoustic Black Holes", Roberto Balbinot, Alessandro Fabbri, Richard A. Dudley, Paul R. Anderson https://arxiv.org/abs/1910.04532: "Phonon creation inside the horizons of acoustic black holes is investigated using two simple toy models. It is shown that, unlike what occurs in the exterior regions, the spectrum is not thermal." This is extremely serious, since it is the correlations between interior and exterior modes that is at the *very heart* of the Hawking effect.

11. The entropy of the physical system behind the acoustic barrier is not proportional to the area of the barrier.

None of this necessarily puts paid to the usefullness and fruitfulness of the analogy. It is necessary, however, that it be explicitly checked, at least theoretically but optimally experimentally as well, that these disanalogies don't effect the results in a disfavoring way. (Norton's material theory of induction would be useful to invoke and deploy here, on the importance of detailed knowledge peculiar to the domain of interest for supporting inductive judgments.)