On some curious features of white holes

Abstract

Possibility of black hole mergers naturally leads to questions concerning their white hole analogues. This question becomes particularly interesting in the context of "black hole fireworks" proposals, according to which black holes can tunnel to white holes.

White hole is defined as a time-reversed counterpart of a black hole. There are quite a few reasons for being worried about white holes. Three of them seem to be standard:

1. there is a number of astrophysical objects which are candidates for black holes, but no one ever observed a candidate for a white hole,[1] This fact is often followed with the sentiment that (therefore) white holes must be unphysical (perhaps standard moves will suffice to explain the asymmetry between black and white holes, perhaps not; cf a state of the art overview of the discussion on advanced and retarded Green's functions in Smith (2013)).[2]

2. white holes are super indeterministic objects, in the sense expressed by Penrose (1979) (which, on the philosophy side, Earman (1995) seems to endorse):

   > The future behavior of such a white hole does not, in any sensible way, seem to be determined by its past. In particular, the precise moment at which the white hole explodes into ordinary matter seems to be entirely of its own 'choosing', being unpredicatble by the use of the normal laws of physics.

3. white holes tend to massively violate second law of horizon thermodynamics (and, presumably, also generalized second law), because the area of a

[1]Even though every now and then somebody tries to present a Big Bang-type event as a white hole.

[2]In particular, it could be fun to consider this question in the context of analogue models of black holes, such as those proposed by Unruh.

horizon of a (classical) white hole will be decreasing or constant at best (simply because area of a classical black hole horizon is increasing or constant).

I will now oftter a fourth reason. Consider a black hole merger, a situation which (presumably) can be encountered in binary black hole systems. Schematically, black hole merger (such as recent GW150914 event) could be described as collision of two massive black hole, which produces third black hole and emitts some mass in the form of gravitational waves. Symbolically:[3]

$M_{BH1} + M_{BH2} \rightsquigarrow M_{BHfinal}$ + some energy emitted

Where squiggly arrow denotes physical process interpolating between state on the left hand side (two black hole states before merging) to the state on the right hand side (single black hole after merging). Recall that white holes are (by definition) time reverses of black holes; so one can take the time reverse of the black hole merger, and (by time reversal invariance) obtain some solution of general relativity. What happens in the time reverse of the merger? Seemingly, a single white hole splits into two smaller white holes, $WH_{initial} \rightsquigarrow WH1\&WH2$. I will call this a white hole splitter. By time reversal symmetry, white hole splitter is a solution of classical GR. We have, then, the following relation between masses of white holes obtained in the split:

$M_{initial}$ +time reverse of (some energy emitted) = $M_{WH1} + M_{WH2}$

But what could be time reverse of emitted energy? It seems that during split white hole sucks in energy from its vicinity, in a form of "inverse" gravitational waves which converge on the splitter (instead of emerging from it, as they do in the black hole merger).

That white hole splitters are possible, at least to the extent to which white holes are permitted by classical general relativity, follows immidiately from the definition of a white hole. So the issue of white hole splitters is not specific to black hole fireworks scenario I will discuss below. But in the context of black hole fireworks worries concerning white holes seem to be more pressing. After all, no one else suggests that white holes are an important element of the physical

[3]Note that this assumes that mass of each black hole is a well-defined and conserved physical quantity, whereas — due to non-existence of local gravitational energy in classical GR — in fact it is not. Even though there are multiple proposals on the table for a global, or quasi-local, or frame-dependent description, I am not aware of application of them to clarify the notion of mass used in standard expositions of black hole collisions. In case of GW150914, LIGO collaboration always speaks about number of Solar massess in the detector frame (Abbott et al. (2016)).

model.[4]

By black hole fireworks I will refer to a recently proposed theoretical scheme (Haggard and Rovelli (2015), Rovelli and Vidotto (2014)), according to which quantum effects cause black holes to tunnel into white holes.[5] It seems that if black holes tunnel to white holes, then some black holes, for instance black hole mergers, should be able to tunnel into white hole splitters.[6]

Having a white hole splitter in one's theory is at best a mixed blessing. It could be a blessing, because finding a signature of a hypothetical signal from a black-to-white hole tunneling may turn out to be easier if one has a splitter available.[7] And, certainly, if such tunneling is possible, explanation of the asymmetry between black and white holes is no longer necessary.

The other two standard worries remain. In a sense, one deals with indeterminism presented by singularities hidden inside black holes by proposing indeterminism regurtitated from the interiors of white holes. And one violates the second law of horizon thermodynamics. The possibility of white hole splitter raises additional uncomfortable questions. It seems that one either needs to deny that white hole spitters are possible (even though white holes themselves are), or provide an explanation for their weird features (that is, converging gravitational waves sucked in from the environment). After all, it is clear why two black holes would merge: there is a gravitational interaction which brings them together. But what would make a white hole split? One could speculate, for example, that:

1. white holes split, because they are inhomogenous (taking this route would require one to explain somehow violation of the white hole versions of "no hair" theorems), or that

2. white holes do not split, because such a split is statistically unlikely (which, in turn, requires that one provides at least a physically relevant statistics of such events), or that

3. even though the theory allows for having time reversed analogues of objects, not every process and property (which could be ascribed to a black hole) has a time-reverse analogue — so even though there are black holes and there

[4] Of course, if some other model making use of white holes would be suggested, an reply to three standard worries and possibility of white hole splitters would be necessary.

[5] Do not confuse that with a black hole firewalls!

[6] Perhaps one can also imagine single black hole tunelling to a splitting white hole, even in the absence of merger in the past history of the black hole. After all, if a white hole splitter region could be glued to a black hole region resulting from a black hole merger, it could also be glued to an equally massive black hole which is not a result of the merger. Or so it seems.

[7] At the very least, the way a splitter suspiciously sucks in energy should provide one with a distinct signature.

are white holes, black holes can merge whereas white holes cannot split, or note that

4. I assumed that black hole fireworks can be used to glue a white hole splitter to a black hole merger, and argue that this is unacceptable [8]

While black holes attract a lot of attention, their time reversed cousins were not as lucky. I have argued that there are interesting puzzles specific to white holes, which may become more pressing for a black-to-white hole tunneling scenario. Some of these puzzles, I believe, will remain with us even if black hole fireworks turns out to be unviable. On whether white hole splitters demonstrate the unviability of the black hole fireworks, I remain agnostic.

References

Abbott, B., Abbott, R., Abbott, T., Abernathy, M., Acernese, F., Ackley, K., Adams, C., Adams, T., Addesso, P., Adhikari, R., et al. (2016). Observing gravitational-wave transient gw150914 with minimal assumptions. *Physical Review D*, 93(12):122004.

Earman, J. (1995). *Bangs, crunches, whimpers, and shrieks: singularities and acausalities in relativistic spacetimes*. Oxford University Press, New York, NY.

Haggard, H. M. and Rovelli, C. (2015). Quantum-gravity effects outside the horizon spark black to white hole tunneling. *Physical Review D*, 92(10):104020.

Penrose, R. (1979). Singularities and time-asymmetry. In *General relativity*.

Rovelli, C. and Vidotto, F. (2014). Planck stars. *International Journal of Modern Physics D*, 23(12):1442026.

Smith, S. R. (2013). Causation in classical mechanics. *The Oxford handbook of philosophy of physics*, pages 107–140.

[8] It would be interesting to see a principled reason why such a gluing could be unacceptable. Of course, as things stand, black hole fireworks has been applied to Schwarzschild black holes, because in that case a classical Haggard metric interpolating between black hole and white hole solution has been found. I assumed that black hole fireworks applies universally to other types of black holes — in particular, Kerr-type, both in solitary and in binary configurations (insofar as it makes sense to speak about Kerr type black hole in binary configuration). If that would turn out not to be the case, the usefulness of black hole fireworks would be limited to the point of being useless.