Curious features of white holes

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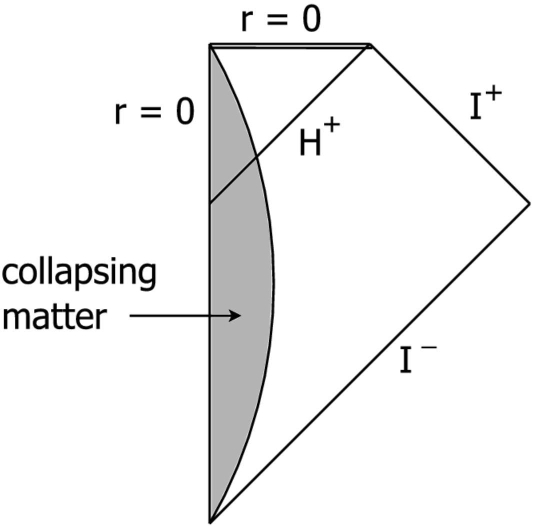
Section 1

Intro: white holes

Black hole: a diagram



What are white holes?

General relativity is invariant under time reversal in the following sense: take a time orientable spacetime $\langle M, g_{ab} \rangle$ with chosen temporal orientation, and change all of the past-pointing vectors to be future-pointing and vice versa; the result is a new spacetime $\langle M, g'_{ab} \rangle$. So: change of temporal orientation of a model of GR results in (usually: non-equivalent) model of GR.

Do that to a spacetime with a black hole, and you get what is called a white hole.

How to think of a white hole? Loosely speaking: instead of
- gravitational collapse of ordinary matter imploding to massive something with horizon, which pulls in matter and contains future singularity,
you have
- a massive something with horizon, spitting out matter, with past singularity, which disappears by transitioning to ordinary matter.

Section 2

Some issues with white holes

White holes are unphysical - but why, exactly?

That white holes are unphysical is something like a consensus (and I will not try to undermine this consensus). But which features of white holes are the basis for the consensus?

First try

UNSEEN: nothing remotely resembling a white hole has ever been observed (with one exception: early and since dismissed quasar models).

This leads to questions concerning ASYMMETRY: why such a huge proportion of models of GR is useless as a physical description, whereas their time reversed counterparts are useful? Is this asymmetry different from asymmetries present in other physical theories? ([Smith, 2013], [Earman, 2013] for GR; *prima facie* it seems that white holes are unlike advanced/retarded potentials, or thermodynamical asymmetries)

One could try to explain UNSEEN using UNSTABLE. [Eardley, 1974] (subsequently: [Blau, 1989], [Barrabès et al., 1993], [Ori and Poisson, 1994]): accretion of small amounts of matter around white hole leads to gravitational collapse.

Digression: every now and then someone tries to interpet Big Bang as a white hole. And, actually, Eardley's motivation was interpretation of white holes as a sort of delayed pieces of Big Bang.

Second try

INDETERMINISM. [Penrose, 1979]: "(t)he future behavior of (...) 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 unpredictable by the use of the normal laws of physics"

Indeterminism Penrose is worried about seems to be a form of multiple allowed continuations: fix an initial spacetime region containing a white hole (this cannot be Cauchy). How many continuations of the initial region exist? Plenty: explode immidiately, continue for some time and then explode, never explode. So when constructing a model and trying to predict what happens next, should I continue with a white hole or an explosion? On what grounds should I decide that?

The theory is silent about these questions.

Second try, cont'd

INDETERMINISM is related to NAKED SINGULARITIES and (some versions of) cosmic censorship hypothesis.

[Earman, 1995] on naked singularities: problem with them is that "all sorts of nasty things – TV sets showing Nixon's 'Checkers' speech, green slime, Japanese horror movie monsters, etc. – emerge helter-skelter from the singularity"

Digression: note that a concept of naked singularity is tricky, and is usually ([Manchak, 2013]) restricted to future directed incomplete curves; under the standard notion white holes are not nakedly singular.

Third try

NO 2ND LAW: white holes violate second law of the horizon thermodynamics – area of the horizon of a white hole is non-increasing (because area of the horizon of a classical black hole is non-decreasing) (possibility of a no-go result [Wall, 2013]-style?) ([Zeh, 2013] seems to be subscribing to the view that white holes are unhpysical for general thermodynamical reasons).

Digression: but opinions on that vary, for instance [Kiefer, 2007] does not think that white holes violate 2nd law, because he considers 2nd law to concern future horizon of black hole, and (analogously) past horizon of white hole. But why is it OK to make 2nd law only about certain types of horizons?

Section 3

Splitters

Binary black holes

Consider a collision of a binary black hole system, during which a single black hole is formed, and some amount of energy is emitted as gravitational waves. Schematically, we have a sequence of metrics with two black holes converging to a metric with a single black hole (which is highly non-trivial, cf [Pretorius, 2005], [Gallouin et al., 2012]),

which can be though of as a process: $BH1 \oplus BH2 \rightsquigarrow BHfinal \oplus$emitted energy,

during which: $M_{BH1} + M_{BH2} = M_{BHfinal}+$emitted energy

A time reverse of a spacetime describing black hole merger is also a spacetime. I will call it a white hole splitter (so, SPLITTERS).

Gravitational waves for splitters

In a white hole splitter we have:

a process: $WHinitial \oplus$time reverse of (emitted energy)$\rightsquigarrow WH1 \oplus WH2$

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

So, it seems that instead of gravitational waves emitted from the merger event, a splitter event sucks in energy from the environment (converging gravitational waves instead of emitted gravitational waves). One could sort of "overcharge" a white hole and split it.

More general question: why would a white hole split?

Black holes merge, because they are gravitational objects interacting with each other. But (since we have white hole versions of no hair theorems) white hole is uniquely characterized by three parameters. "Overcharge" is controlled by converging gravitational waves. But is there any physical mechanism for the split itself, once the energy is provided?

Section 4

Black hole fireworks

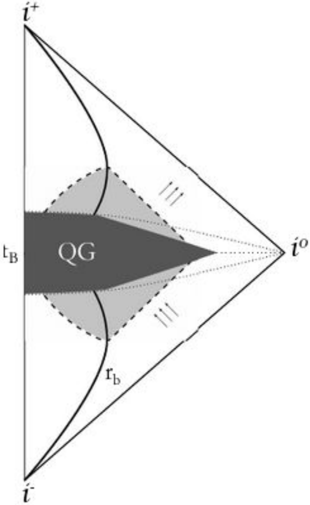
What are black hole fireworks?

It is a variant of the cosmological quantum bounce scenario applied to black holes. According to black hole fireworks, semi-classical evaporation of a black hole due to Hawking radiation is followed by period during which non-perturbative quantum gravitational effects in a finite region R lead to a repulsive bounce to a time-reverse of the black hole solution ([Hájíček and Kiefer, 2001], [Rovelli and Vidotto, 2014], [Haggard and Rovelli, 2015], [Barceló et al., 2016]; see [Malafarina, 2017] for a recent overview and [Vidotto et al., 2016] for suggestions concerning observable signals).

The life of a black hole looks like this: formation, semi-classical evaporation, full quantum gravitational effects lead to tunneling, white hole phase, explosion into ordinary matter. After the explosion singularity disappears.

Time symmetric version: region with non-perturbative effects is followed by an exact time reverse of the spacetime metric describing formation phase.

Diagram for black hole fireworks



A consequence

If black holes can tunnel into white holes, then some black holes can tunnel into white hole splitters. Time symmetric black hole fireworks leads to SPLITTERS. A recipe:

Start with a binary black hole system.

Merge to a single black hole.

Wait until it stabilizes.

Assume that you get approximately Schwarzschild black hole (this is only because, as far as I know, schemes for black-to-white hole tunneling which are available at the moment only work for Schwarzschild black holes; but they should generalize).

Evaporate.

Tunnel into a white hole through R.

Glue time reverse of everything before the tunneling (and because we started with a merger, we should continue with a splitter).

So one has to either drop time symmetric black hole fireworks or accept and somehow explain the possibility of SPLITTERS.

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Section 5

Partial summary

An advice on what you should think about white holes in GR:

1. white holes are much more tricky than it is usually suggested,
2. INDETERMINISM, SPLITTERS, NAKED SINGULARITIES and NO 2ND LAW are not that much of an issue, beacuse white holes are UNSEEN,
3. ASYMMETRY and UNSEEN call for an explanation.

An advice on what you should think about white holes assuming black hole fireworks:

1. UNSEEN is no longer an issue,
2. ASYMMETRY stays (black holes tunnel into white holes, but not the other way round; plenty of black holes around, not so many white holes: why?),
3. INDETERMINISM, NO 2ND LAW and SPLITTERS are serious issues which should be addressed (perhaps by understanding spacetime geometry as an effective description?),
4. in a sense, we have what (effectively) looks like NAKED SINGULARITIES in the domain in which classical GR is valid; in that sense, under black hole fireworks some versions of the cosmic censorship have (effectively) to be false (and in its domain of validity, GR becomes more indeterministic than it would be without black hole fireworks - even if overall we have less indeterminism).

A philosophical consequence: are white holes physical or unphysical?

Imagine that you draw a divide between spacetimes which are useful physical representations of the way spacetime could be, and those which are "physically unreasonable".

White holes are an example of how such a divide changes when additional hypothetical quantum gravitational mechanisms are postulated. Not only spacetimes with white holes suddenly land on the "reasonable" side of the divide; relative importance of various physical features of these spacetimes shifts.

An interesting philosophical consequence is that white holes and black hole fireworks give us an example of how acceptance of a hypothetical quantum gravitational scenario forces us to revise interpretational assumptions and assessments concerning certain spacetimes, in such a way that spacetimes thought to be unreasonable in GR become reasonable in QG.

Section 6

(Oscillations)

White hole instability and black hole fireworks

Recall white hole instability of [Eardley, 1974]: accretion of small amounts of matter around white hole leads to gravitational collapse. This effect is primarily driven by the matter content in the exterior of black hole.

Digression: white hole instability results assume that the white hole is Schwarzschild, but conveniently, that a black hole is Schwarzschild is also assumed in the black hole fireworks.

Improved model: black-white hole oscillations

In the light of this, how should one construct the spacetime metric once genuine quantum gravitional effects become negligible (i.e. once the spacetime diagram contains initial part of the white hole region)? Because classical general relativity with semi-classical corrections applies to early and intermediate stages of black hole lifetime, it seems reasonable to assume that classical general relativity applies to intermediate and late stages of white hole lifetime. If so, the white hole phase needs to be followed by re-collapse.

Then, life of a black hole looks like this: formation, semi-classical evaporation, full quantum gravitational effects lead to tunneling, white hole phase, collapse into a black hole, semi-classical evaporation, and so on. The system oscillates between black and white hole states (with multiple copies of R interpolating).

Consequences of the black-white hole oscillations model

1. there is no burst, because most of the white hole mass (and the expanding shell) is captured in the re-collapse phase,
2. the burst signal is replaced by a redshift-blueshift oscillations,
3. relative time spent in the black and white hole phases varies, depending on the amount of mass in the exterior and proportion of mass emitted through Hawking radiation,
4. since black-white hole oscillations amounts to smoothly patching together an infinite sequence of metric each of which contains a singularity, there is a sense in which (something like a) singularity remains in the model (and it seems that black hole fireworks taking into account the white hole instability fails to be a successful singularity resolution) (but what is a successful singularity resolution, anyway?).

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