BLACK HOLES IN THE PRESENT TENSE.

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Abstract. General relativity does not offer a meaning to 'at the same time in a different place'. This paper examines what might be implied or inferred from the use of the present tense. I start by looking at Schwarzschild space to show that the oft made statement that "There *is* a singularity at the centre of a black hole" is misleading. I use this as a starting point for exploring the notion of a moment in time.

1. Defining the present tense

Suppose a volume of space/time can be described as a volume of space evolving over time. The time coordinate then gives an ordering of events in the space/time. This ordering need not be significant, but such an ordering is implicit (for example) in the statement 'the light we see from Proxima Centauri left that star about 4.22 years ago'.

2. Schwarzschild space and the Oppenheimer Snyder model

In 1939 Oppenheimer and others were interested in the possibility that a star would collapse under its own gravity. In the Sept '39 Physical Review, Oppenheimer & Snyder calculated how this collapse would appear to a distant observer.[1] They looked at the star using co-moving coordinates and showed that it collapses to a singularity in finite proper time. They looked at the same star from a Schwarzschild exterior and showed that it takes an infinite time to collapse to the gravitational radius.[2] Finally they showed how the Schwarzschild time can be derived from the proper time, and showed that the Schwarzschild time goes imaginary when the cloud shrinks through the gravitational radius.[3]

The Oppenheimer & Snyder ideas have since been simplified, extended and cleaned up by others, but the result is still ascribed to Oppenheimer & Snyder. A GRwiki page[4] shows how a single time coordinate t'' ranging from 0 to π can describe the collapse of a dust cloud to a singularity, and:

[1]Text available at `https://journals.aps.org/pr/pdf/10.1103/PhysRev.56.455`

[2]The gravitational radius is now more often called the Schwarzschild radius, or the apparent horizon

[3]See equations 32 in their text, where $ln\frac{r^{\frac{1}{2}}+r_0^{\frac{1}{2}}}{r^{\frac{1}{2}}-r_0^{\frac{1}{2}}}$ goes imaginary when $r < r_0$. Equations 33 and 34 tell us that r_0 is the gravitational radius.

[4]`http://grwiki.physics.ncsu.edu/wiki/Oppenheimer-Snyder_Collapse`: for the readers convenience I have appended a copy of the GRwiki paper.

for $t'' < \pi/2$, Schwarzschild time (t) can be derived from t'';
as t'' goes to $\pi/2$, t goes to infinity;
at $t'' = \pi/2$, an event horizon forms;
for $t'' > \pi/2$, t is imaginary;
at $t'' = \pi$, the singularity forms.

Neither the event horizon nor the singularity can form while Schwarzschild coordinates can still describe the surrounding space. More important for consideration of tense, the surface of infinite red shift at the Schwarzschild radius cannot form. A surface of infinite red shift is an *enduring moment*, a surface that does not change with time, so nothing can fall through it.

The Schwarzschild coordinates assume spherical symmetry, but there is no reason to suppose that losing that symmetry would allow an enduring moment to form, let alone a singularity. The implied reliance on spherical symmetry can be removed by changing to independent Cartesian-like x,y,z spacial coordinates. We could then map (say) the Milky Way, and the black holes in the Milky Way would presumably all be eternally on the point of collapse. From time to time stars merge, and when two black holes merge the collapsing interiors suffer gross distortion in seconds of an observer's time, but picoseconds or less of proper time, and the result will, again presumably, be a star at the point of collapse. If you accept that the black holes merge before their interiors have collapsed in this coordinate system then they must do so in all coordinates systems, and it is therefore incorrect to say there *is* (now) a singularity at the centre of a black hole.

You may wonder how black holes are modelled, and whether the model is compromised by an incorrect assumption that there is a singularity at the centre. I have listened to people who have modelled the merger of black holes, and if I have understood them correctly, they treat the black hole as if it were one half of an Einstein Rosen bridge. From the exterior the difference is undetectable. One might expect there could be some difference when two black holes merge, but the successful detection in 2015 of the gravitational wave caused by such an event suggests otherwise.

3. A time orderable space

I proposed that where a volume of space/time can be described as a volume of space evolving over time, a time slice can be considered as a moment in time dividing the past from the future, but there are further conditions to be met. There must be no enduring moments since at such places the time parameter does not identify a time slice. Also, the space associated with a time slice must be continuous. Finally, the space/time must be realistic, meaning that the space includes the presumed observer,[5] and the presumed observer endures in the space, and does not (for example) merely fly through it at high speed.

For want of a better term I will call this space/time a *time orderable space.*

[5]The presumed observer will generally be the audience or reader.

4. A speculation: could there be a universal order?

When we work with a small volume of space/time we have a lot of flexibility in the choice of coordinate system, but some choices are more easily extended than others to a larger volume.

The greater the volume of space/time covered by the coordinate system, the less flexibility there is in the choice of system. It is tempting to speculate how large a volume of space/time might be time orderable.

If the entire universe is time orderable and the universe is infinite, then the ordering is presumably unique. There are many reasons to doubt this, but perhaps as with maximally extended black holes those reasons may prove to be founded on something unphysical. The idea is philosophically appealing, being very Machian.

The least unbelievable of the thoroughly unbelievable explanations of 'spooky action at a distance' requires a large volume of space to contribute to an action 'at the same time'. While still not suggesting a mechanism, a unique time ordering of the universe would offer a possible meaning for that supposed time slice. The spooky action at a distance associated with entangled particles may seem exceptional, but spooky action at a distance is inherent in any observation.[6]

5. A speculation: on the ultimate evolution of black holes

To quote from astronomy.com[7] "In (`https://arxiv.org/abs/1805.04317`), astronomers from the Australian National University (ANU) announced the discovery of the fastest-growing black hole ever found. The supermassive black hole, estimated to have the mass of about 20 billion Suns, is growing by around one percent every million years, which means its devouring a Sun's worth of matter every two days."

The space inside the black hole will be repeatedly churned, and it might be expected that it becomes very uniform. Ultimately, the black hole could turn white.[8] An enormous uniformly distributed mass undergoing sudden rapid inflation sounds at least reminiscent of the start of the known universe.

6. The Oppenheimer & Snyder legacy

There seems to be a belief among even those expert in the field of cosmology that a black hole has (not merely will have) a singularity at its centre. I failed to find an entirely unambiguous statement to that effect in a text book, so I had assumed that this expression was metaphorical, but it does seem to be taken literally. `https:`

[6]For a justification of this assertion, see "On the Dichotomy of Causality and Measurement." at `http://viXra.org/abs/1805.0166`

[7]urlhttp://www.astronomy.com/news/2018/05/snapshot-second-gaia-release-results-so-far

[8]If, as argued above, there is no event horizon, then the Bianchi identities do not prohibit the switch from black to white hole. Assumptions such as the the Hawking & Ellis dominant energy condition may do, but they are indeed assumptions.

//en.wikipedia.org/wiki/Black_hole#Singularity says "At the center of a black hole, as described by general relativity, lies a gravitational singularity". Furthermore, I have found in conversation that people feel that this follows from the Oppenheimer & Snyder paper.

According to https://arxiv.org/abs/1703.04234v1, "Oppenheimer's research on black holes [was initially neglected] by the scientific community, and even by Oppenheimer himself.". Perhaps Oppenheimer 'neglected' his research because his paper "[sought] to find the asymptotic behaviour of [the metric] for large values of [Schwarzschild time]",[9], and he felt that before Schwarzschild time reaches infinity his analysis loses physical relevance.

There is an assumption that the world line cannot just end at a specific point in space. Given a dust cloud and a Schwarzschild exterior the world line of a speck of dust appears to end at a specific point in space, so it can be argued that it must continue down to the singularity. If that is the thinking, it is illogical. If the dust continued down to the singularity then its world line would indeed end at a point, but the Oppenheimer & Snyder model becomes unrealistic long before Schwarzschild infinity so the world line of the speck of dust continues but the continuation is unknown. It is not absolutely impossible for any speck of dust to escape, perhaps as the black hole turns white. It has been argued (to a different end) that the location of an event horizon depends on the whole of space/time. When we consider the whole of space/time, it becomes questionable whether an event horizon ever forms around a black hole.

Gut feel may explain why some people assume that a singularity forms. Before a pair of black holes merge, they will typically be circling each other with a period less than one second[10] and it is hard to grasp that when they, at least apparently, plunge together in less than one rotation, that plunge takes forever in the observer's time.

7. Summary

I have shown that the statement that there is a singularity at the centre of a black hole is wrong. The mistake arises from the use of a coordinate system which becomes unrealistic because it ignores the wider universe. I have introduced the notion of a time orderable space which allows us to talk meaningfully about the current state of some distant part of the universe.

I have raised the possibility that black holes have a simpler topography than the current literature assumes, but have a much more complex curvature and future. Similarly, the idea that the entire universe might be a single orderable space is intriguing.

[9]See around equation 37
[10]See for example https://www.soundsofspacetime.org/detection.html

8. Appendix: the GRWiki paper, plus a bit of working.

These notes were written by way of adding explanation to:
`http://grwiki.physics.ncsu.edu/wiki/Oppenheimer-Snyder_Collapse`
the text of which follows after.

The grwiki Oppenheimer/Snyder collapse uses a co-moving metric to describe the interior of the dust cloud:

$$ds^2 = -dt'^2 + A^2[d\chi^2 + sin^2\chi d\Omega^2]$$

They choose to make the squared interval ds^2 have the opposite sign to that in the metrics used by Oppenheimer & Snyder, but the sign is arbitrary as long as you are consistent once the sign is chosen.

χ indexes a spherical surface, and χ_{s0} indexes the surface of the dust cloud. The space is positively curved inside the dust cloud, and $0 \leq \chi \leq \chi_{s0} < \pi/2$.

The corresponding Schwarzschild exterior has line element:

$$ds^2 = -(1 - R/2M)dt^2 + (1 - R/2M)^{-1}dR^2 + R^2d\Omega^2$$

R_s is the value of R at the surface of the dust cloud, and $R_s(0)$ is the value of R at the surface of the dust cloud when it starts to collapse.

A time-like parameter t'' is chosen from which t, R_s, and t' can be derived.

t goes imaginary at:

$$\begin{aligned}
tan^2(\frac{t''}{2}) &= \frac{R_s(0)}{2M} - 1 \\
sec^2(\frac{t''}{2}) &= \frac{R_s(0)}{2M} \\
cos^2(\frac{t''}{2}) &= \frac{2M}{R_s(0)} \\
(cos^2(\frac{t''}{2}) - sin^2(\frac{t''}{2})) &= \frac{4M}{R_s(0)} - 1 \\
&= cos(t'') \\
\frac{R_s(0)}{2}(1 + cos(t'')) &= 2M \\
&= R_s
\end{aligned}$$

And $R_s = 2M$ is the gravitational radius.

Oppenheimer-Snyder Collapse

From GRwiki

Oppenheimer-Snyder collapse is the gravitational collapse of a uniform ball of dust. The initial areal radius of the ball is $R_s\left(0\right)$ and the ADM mass is M . The Oppenheimer-Snyder solution is a piecing together of two other exact line element solutions at the surface boundary of a uniform spherical ball of uncharged dust. The external solution is the Schwarzschild solution. Internal to the matter the solution is the closed Fiedmann line element

$$ds^2 = -dt'^2 + A^2\left[d\chi^2 + \sin^2\chi\, d\Omega^2\right]$$

"To model a pressureless ball" the A and t' are then parameterized in terms of a timelike coordinate t'' according to

$$A = \frac{1}{2}A_0\left(1 + cost''\right)$$
$$t' = \frac{1}{2}A_0\left(t'' + sint''\right)$$

where matching boundary conditions we relate A_0 to the initial Schwarzschild radial coordinate radius of the matter by

$$A_0 = \sqrt{\frac{R_s^3\left(0\right)}{2M}}$$

and have

$$\sin\chi_{s0} = \sqrt{\frac{2M}{R_s\left(0\right)}}$$

The Schwarzschild radial coordinate radius of the matter as a function of our timelike coordinate parameter is

$$R_s = \frac{1}{2}R_s\left(0\right)\left(1 + cost''\right)$$

And the Schwarzschild time evaluated at the surface can be related to our timelike coordinate parameter by

$$t = 2Mln\left(\frac{\sqrt{\frac{R_s(0)}{2M}-1}+tan\left(\frac{t''}{2}\right)}{\sqrt{\frac{R_s(0)}{2M}-1}-tan\left(\frac{t''}{2}\right)}\right)+2M\sqrt{\frac{R_s\left(0\right)}{2M}-1}\left(t''+\frac{R_s\left(0\right)}{4M}\left(t''+sint''\right)\right)$$

and the Kerr-Schild coordinate velocity of the surface with respect to the remote observer is finally

$$v = \sqrt{\frac{\frac{2M}{R_s}-\frac{2M}{R_s(0)}}{1-\frac{2M}{R_s(0)}}}$$