<u>On the 2020 Physics Nobel Prize</u>

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Abstract

The purpose of this note is to draw attention to several open issues related to Penrose's singularity theorem of 1965.

Key words: singularity theorems, incomplete geodesics, Cauchy hypersurface, trapped surfaces, Black Holes, General Relativity, Quantum Gravity.

The distinguished theorist Roger Penrose has recently shared half of the 2020 Physics Nobel Prize for his theoretical work on the Black Hole (BH) singularity problem and its connection to General Relativity (GR). The formal announcement of the Nobel Prize Committee acknowledges that "*Penrose's discovery of the singularity theorem showed that black holes are a robust consequence of the theory of general relativity, forming naturally in very overdense regions*." [1].

In our view, it is important to bring up several lesser known aspects of Penrose's singularity theorem that remain open for debate. In particular,

1) In general, the description of BH dynamics rests on the tacit hypothesis that the spacetime continuum of strong-gravitational fields conforms to the non-Euclidean geometry of *smooth manifolds*. This hypothesis is likely to fail near the event horizon of supermassive BH's. It is conceivable that the onset of ***far-from-equilibrium***

conditions and of a ***transient regime of large metric fluctuations*** falls entirely outside the low-energy framework of GR and conventional field theory.

2) The N-body problem of celestial mechanics leads to ***Poincaré resonances*** and the issue of ***non-integrability and chaos***, overlooked by the majority of models on gravitational collapse [2-4]. In these dynamic regimes, the very notions of trajectory, geodesic or trapped surfaces are likely to become ill-defined, break down entirely or require significant review.

3) Penrose's work shows that inside of the event horizon the radial direction is time-like and time ends at the singularity. As a result, "space" is alleged to turn into "time" inside the singularity. However, this statement makes sense if (and only if) the union of space and time survives inside the singularity, which means that the concept of speed of light in vacuo maintains its traditional meaning below the horizon. This may not be the case if the singularity exhibits ***non-trivial topology*** and is ***no longer differentiable*** in the conventional sense.

4) Ref. [5] shows that 'The presence of a ***Cauchy hypersurface is not guaranteed*** as was shown by Penrose in another influential paper [247] —published almost simultaneously with [248]— where he discovered that plane waves in GR do not admit Cauchy hypersurfaces. Whether or not physically realistic spacetimes are globally hyperbolic is related to the so-called strong cosmic censorship conjecture". There are some indications today that the strong cosmic censorship conjecture may be wrong [6].

5) Along the same lines, [5] also remarks that "… the ***initial/boundary condition*** is absolutely essential in the theorems. Whether or not the initial or boundary

condition is satisfied by actual physical systems is debatable. We will probably never know if the entire Universe —not only the observable one— is spatially finite, or strictly expanding now. Thus, the formation of closed trapped surfaces in the collapse of physical systems given some realistic initial conditions has become the main area of research to elucidate this question, see end of subsection 7.2. One can also follow a similar program, towards the past, in the case of the expanding Universe. Of course, the formation of closed trapped surfaces may depend critically on the given initial conditions, so that this is an area of active research and great relevance in numerical and mathematical relativity now, see section 6."

6) Finally, following [5], one learns that "A very important line of research arises from the ***tension between the singularity theorems and the (yet unfound) theory of quantum gravity***. It is widely accepted that the existence of classical singularities signals a breakdown of the classical theory at extreme conditions, which is precisely when gravitational quantum effects will become relevant. Thus, there is a need to clarify if the singularity theorems, or part of them, can survive when entering into a quantum regime, or if they then simply vanish altogether. For a general discussion, see [35]"

We close by quoting the summary statement of [1] which goes on to caution that:

"*The extent to which the structure of a black hole surrounded by an event horizon actually match the predictions of general relativity is still an open question. Nature may still have surprises in store*."

References

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