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Nicolae Sfetcu

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Email: nicolae@sfetcu.com

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Gravitational Singularities

Within the classical theory of Newton's gravity there is the fundamental possibility of singularity. No signal can propagate from within a singularity, but its gravitational influence is permanently present externally and depends only on the total mass, the angular momentum, and the electric charge of the singularity. Singularities can be detected by the influence of their strong gravity in the immediate vicinity.

In the classical theory of Newton's gravity, an energy argument tells us that there is a speed of escape from the surface of any object.

In Newtonian theory, gravity is described by potential. Similarly, in GR, the symmetrical external (time independent) solution, called Schwarzschild spacetime, depends only on the mass of the inner object. The Schwarzschild radius in GR is the maximum radius of a surface under which light can no longer escape. This "horizon radius" is, coincidentally, the same as the critical ray for objects in Newtonian "singularities".

Gravitational singularities in GR are spacetime locations where the gravitational field becomes infinite. Scalar invariant curves of spacetime include a measure of matter density. Some physicists and philosophers believe that because the density of matter tends to become infinite in singularity, spacetime laws are no longer valid there.

A gravitational singularity almost universally accepted in astrophysics and cosmology as the earliest state of the universe, is the Big Bang. (Wald 1984) In this case also, the known laws of physics are no longer valid. (S. Hawking 2012)

GR predicts that any object that goes beyond a certain point (for stars, the Schwarzschild radius) forms a black hole with a singularity, with an action limit defined by an event horizon. (Curiel and Bokulich 2018) Penrose-Hawking's theorems of singularity state that in this case geodesics end in singularity. (Moulay 2012)

The theory of loop quantum gravity suggests that singularities cannot exist (Gambini, Olmedo, and Pullin 2013) because, due to the effects of quantum gravity, there is a minimum distance beyond which the force of gravity is no longer increasing.

The Schwarzschild solution to the GR equations describes a non-rotating, uncharged black hole. In convenient coordinate systems, part of the metric becomes infinite at event horizon. In a rotating black hole (Kerr black hole) the singularity appears on a ring and can become theoretically a "wormhole". (Wald 1984)

A special type of singularity is the "naked singularity" which, although it is forbidden by the cosmic censorship hypothesis, in 1991 physicists Stuart Shapiro and Saul Teukolsky performed computer simulations of a planetary rotation of cosmic dust resulting in GR allowing for "naked singularities". (Goswami, Joshi, and Singh 2005) Moreover, the cosmic censorship assertion states that there can be realistic singularities (without perfect symmetries, matter with realistic properties), but they are hidden behind the horizon and thus invisible. [1] (Wald 1984).

Stephen Hawking suggested that black holes can radiate energy, preserving entropy and solving problems of incompatibility with the second law of thermodynamics. This means that the black hole has limited cosmic life.

Paul Townsend states that singularities are a generic feature of GR and are inevitable if a body has gone through a certain stage (Townsend 1997) and also at the beginning of a broad class of expanding universes. (S. W. Hawking 1966) The generic structure of these entities is currently being investigated (for example, BKL conjecture). (Berger 2002)

Regarding the definition of the singularity, there is a clear disagreement: although it changes the local geometry, difficulties arise in speaking of it as something that is found in a certain space-time location, which is why some physicists and philosophers propose to speak of "singular spacetimes" instead of "singularities." The most important definitions refer either to incomplete paths or to the idea of space-time "missing points" or an idea combining the two above concepts, respectively a single structure with "pathological" behavior (spacetime deformation which manifests himself as a gravitational field). (Curiel and Bokulich 2018)

Black Holes

Black holes raise some conceptual aspects. Although they are regions of spacetime, black holes are also thermodynamic entities with a temperature and entropy; and the evolution of the

[1] Restrictions of singularities in the future exclude original singularities, such as Big Bang, which are, in principle, visible to observers at a later cosmic moment. The cosmic censorship conjecture was first presented by Penrose in a work in 1969. (Penrose 1969)

black holes is apparently in conflict with standard quantum physics because it excludes entropy growth. (Curiel and Bokulich 2018)

In the center of a black holes of RG there is a gravitational singularity, a region in which the spacetime curve becomes infinite. Singularity contains the entire black hole mass, resulting in infinite density. (Carroll and Carroll 2004) In the case of a charged (Reissner-Nordström) black hole, or rotating (Kerr) black hole, it is possible to avoid singularity, but it is hypothetical to exit black hole in a different space-time, the black hole acting as a wormhole, and thus the possibility of traveling in another universe or in time. Droz considers this possibility only theoretical, because any disturbance would destroy this possibility. (Droz, Israel, and Morsink 1996) The possibility of time-closed curves around the Kerr singularity leads to causality issues such as grandfather's paradox. (Sfetcu 2018)

According to Kerr, most researchers now consider that there is no obstacle to the formation of an event horizon of black hole. (Kerr 2007) Penrose demonstrated the inevitability of singularities under certain conditions. (Penrose 1965) The Kerr solution, the no-hair theorem, and the laws of GR thermodynamics showed that the physical properties of black holes were simple and comprehensible. (S. W. Hawking and Penrose 1970)

A black hole of stellar mass is formed from the gravity collapse of heavy stars. Another theory is of the early black holes after the collapse of stars in the early universe, and supermassive black holes might have formed from the direct collapse of the gas clouds in the early universe. (Pacucci et al. 2016)

On September 14, 2015, LIGO observer noticed the existence of gravitational waves (LIGO Scientific Collaboration and the Virgo Collaboration 2016) from the fusion of two black holes, this being the most concrete evidence of the existence of black holes so far. On June 15, 2016, there was announced a second detection of a gravity wave event in colliding black holes. (Overbye 2018) In April 2018, LIGO noticed six gravitational wave events that originated from the black hole fusion.

Event Horizon

The defining feature of a black hole is the appearance of an event horizon - a limit in space where matter and light can only pass in one direction, inwardly to the mass of the black hole. (Arnowitt, Deser, and Misner 1962).

The event horizon surface is located at the Schwarzschild radius for a non-rotating body, being proportional to its mass. The minimum mass required for a star to collapse beyond the event horizon is the Tolman-Oppenheimer-Volkoff limit, which is about three solar masses. Astronomers can observe those by detecting accretion discs around them, where matter moves at a rate so high that friction creates high-energy radiation that can be detected. Sometimes, these accretion discs are forcing matter to flow along the black hole spin axes, creating visible jets.

The concept of mass in GR is a problem, as theory does not provide a unique definition of the term, but several different definitions (Hawking energy, Geroch energy, Penrose quasi-local energy–momentum, etc.), are applicable in different circumstances. Basically, it is impossible to find a general definition of the total mass of the system (or energy) in the GR, since the gravitational field energy is not part of the energy-momentum tensor. It is hoped for the future to use a quasi-local mass suitably defined to give a more precise formulation of Penrose inequality for black holes (linking the black hole to the event horizon) and to find a quasi-local version of black hole mechanics laws. (Szabados 2004)

Big Bang

Big Bang theory in cosmology explains the formation of the universe (Overbye 2017), and its expansion from an initial state of very high density and temperature. Big Bang explains a wide range of phenomena, including the abundance of light elements, the cosmic microwave background, the large-scale structure, and Hubble's law (Wright 2009). Basically, Big Bang is an initial singularity, (Roos 2008), the "birth" of the universe.

The problem is that, although these results determine the existence of an initial singularity, they do not provide too much information about its structure. There are partial results for restricted solution classes, e.g. numerical simulations, but the resulting image of original singularity contrasts with that of FLRW models. Also, there may be non-scalar singularities (Ellis and King 1974).

Regarding zero moment of the Big Bang, John Heil asks, "What exactly is *nothing at all*? What would nothing *be*?" (Heil 2013, 174). Heil suggests that the answer depends on how we understand the Big Bang. Bruce Reichenbach (Reichenbach 2017) states that if we reverse the direction of our vision and look back in time, we discover that the universe reaches a state of compression where density and gravitational force are infinite. This unique singularity is the beginning of the universe - matter, energy, space, time and all physical laws. Since the Big Bang initiates the laws of physics itself, one cannot expect any scientific or physical explanation of this singularity. Considering GR, the Big Bang is not an event. An event takes place in a spacetime context. But Big Bang does not have this context. Therefore, the Big Bang cannot be considered a physical event that occurs at some point. Grünbaum supports this position by arguing that events can only result from other events: "Since the Big Bang singularity is technically a non-event, and *t=0* is not a *bona fide* time of its occurrence, the singularity cannot be the effect of any cause in the case of either event-causation or agent causation alike…. The singularity *t=0* cannot have a cause." (Grunbaum 1994)

Silk (Silk 2001, 456) proposes to eliminate the Grünbaum's objection by extending the notion of "event" by eliminating the requirement that it should be relational in a spacetime context. In the Big Bang, the spacetime universe begins and continues to exist in measurable time after initial singularity. Thus, the Big Bang may be considered either as the event of the beginning of the universe, or as a state in which "any two points in the observable universe were arbitrarily close together."

Based on Grünbaum's logic that Big Bang singularity is not an event, Bruce Reichenbach (Reichenbach 2017) argues that since events occur only from other events, events following the Big Bang cannot be the effect of that singularity, resulting in no events, what is absurd.

Are there Singularities?

There is no widely accepted definition of singularity. Physics should dictate what definition of singularity to use, although many definitions can co-exist without problems.

Erik Curiel and Peter Bokulich pose the question of what would mean assigning "existence" to a singular structure under any of the available possibilities. (Curiel and Bokulich 2018) They analyze the possibility of incomplete paths in a maximal relativistic spacetime at a point of spacetime where the path could be expanded by passing through that point. However, they consider the fact that, if it is a failure in our conceptions of spacetime singularity, failure is not in the cosmic space of the present world, but rather in the theoretical description of spacetime.

Gravitational waves are perturbations in the spacetime curve generated by the accelerated masses predicted by Einstein (propagating at the speed of light of the changes of spacetime curves due to the objects in accelerated motion). (Einstein 1918) The distances between objects increase and decrease rhythmically, as the wave goes, at a frequency corresponding to that of the wave. The gravitational waves transport energy as gravitational radiation. Binary neutron star systems are supposed to be a powerful source of gravitational waves during their fusion due to the very large acceleration of their masses. (LIGO Scientific Collaboration and Virgo Collaboration et al. 2017)

The gravitational waves allow the observation of the fusion of black holes and, possibly, of other exotic objects in the distant Universe. (Krauss, Dodelson, and Meyer 2010)

In space-time geometry, FLRW models with ordinary matter have a singularity in a finite time in the past. The singularity theorems (S. W. Hawking and Ellis 2008) state that the existence of an initial singularity is robust: rather than being FLRW-specific or other highly symmetric patterns, singularities are generic in models that satisfy plausible physical assumptions. (Smeenk and Ellis 2017)

The theorems of singularity proven in the 1960s (S. W. Hawking and Ellis 2008) show that the universe is finite in the past in a wide class of cosmological models. Past singularities, signaled by the existence of non-expandable geodesics of limited length, must be present in models with a number of plausible characteristics. Intuitively, extrapolating back from the present, an inextendible geodesic reaches, within a finite distance, to a margin beyond which it cannot be extended. There is no "cosmic time" uniquely defined, but the maximum length of these curves reflects the finite age of the universe. The theorems of singularity apply plausibly to the observed universe, in the field of applicability of general relativity. (Smeenk and Ellis 2017)

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