Science digression: relativistic holes

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Abstract

I introduce the concept of "science digression", which is scientific speculation anchored in established physical theories and experimental knowledges. I distinguish it from the literary-artistic activity called "science fiction" and present some popular examples.

1 Introduction

Science fiction (ScF): the Merriam-Webster dictionary [1] quotes the following. *"Stories about how people and societies are affected by imaginary scientific developments in the future."* As a general rule then when one speaks of "science fiction" one thinks of a "story", an artistic and literary creation. But there is another kind of scientific discourse that I shall call **"science digression"** (ScD). (Warning, not to be confused with "science dissemination", which is a different story.) ScD is the extrapolation of established scientific knowledge by means of the consideration of future possibilities of theoretical, experimental and observational scientific advancements.

ScF is completely free — the artistic activity is free by definition; ScD has limited freedom, because it has one foot on the known laws of natural sciences and other in the "well-educated speculation".

One of the greatest exponents of ScD is the American physicist **Kip Thorne**. He was a student of the great John Archibald Wheeler (1911-2008), who was his mentor both in theoretical physics and in ScD — which, by the way, is a branch of theoretical physics. ScF drinks from the wellhead of ScD and ScD drinks from the wellhead of ScF.

Kip Thorne was the protagonist of a recent episode of ScF and ScD: the movie **Interstellar**. I shall not comment on the movie, but on some ScD aspects present therein. Those interested on the movie might watch Kip Thorne himself talking about it in a curious one-hour presentation in *The Science of Interstellar* [2].

Kip Thorne is also the author of a scientific dissemination book entitled *Black Holes & Time Warps* [3], where one can find the most precious pearls of his crop of ScD, many of them present in Interstellar. My purpose is to comment on some of those pearls, especially **wormholes** (WHs), **time machines** (TMs) and **black holes** (BHs).

In the examples discussed below, namely, WHs, TMs and BHs, the plausibility of the specific ScDs of each case are frequently supported by the belief that we shall achieve in the future a theory of **Quantum Gravity** (QG), that would vindicate and justify the speculations done. This sort of belief — that of the emergence of a more complete theory in the future — is a distinct feature of ScDs in general.

2 Pearls of Science Digression

According to [3, p. 485], WHs were mathematically discovered in 1916 by the Austrian physicist Ludwig Flamm (1885-1964) as a solution of the field equation of Albert Einstein (1879-1955), a few months after Einstein formulated his equation of the General Relativity Theory (GRT). Einstein and the American physicist Nathan Rosen (1909-1995) explored them in the decade of 1930 and Wheeler and his group (which has Kip Thorne as a member) in the 1950s. WHs are the most popular candidates for being TMs in all modern ScDs.

The modern conceptual possibility of the existence of BHs arose also in 1916, as a direct consequence of the work of the German astronomer and physicist Karl Schwarzschild (1873-1916). His solution of GRT's field equation showed a *singularity*, i.e., an infinity result for a given value of the spatial coordinates. Any physical meaning associated to this singularity was rejected by Einstein and by the English astrophysicist Arthur Eddington (1882-1944), the greatest authorities in GRT during the first decades after the formulation of the theory ([3, p. 134]). Only in the 1960s the researches with BHs, as we know them today, began to be done, especially after 1967, when Wheeler coined the term “black hole” ([3, p. 256]).

Next, I shall briefly talk about each of these ScDs.

2.1 Wormholes and time machines

WHs are tunnels through hyperspace (hypothetical space where real space-time is embedded), which connect a space-time region of the universe to another. They are like space-time shortcuts. Its name come from the analogy with the hole that a guava's worm does when it traverses it through its interior. Its path from one point on the guava peel to another point on the peel can in this way be smaller than the path made over the guava peel. Figure 1 shows examples of these two paths.

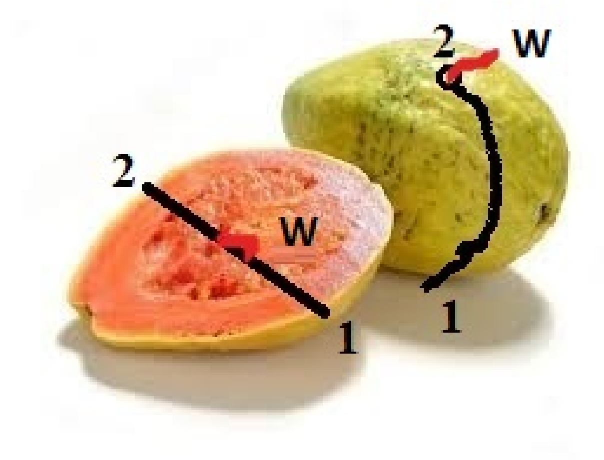

Figure 1: The guava worm W can go from point 1 to point 2 by the two paths shown in the figure. The “wormhole” inside the guava represents the shortest.

Interstellar travels would then be possible, in spite of the enormous distances to the nearest stars. The travel could be done more quickly by a shortcut through the hyperspace with the aid of a WH. Kip Thorne uses another nomenclature in his talk mentioned above: he calls **Brane**, short for “Membrane”, the four-dimensional (3 spatial coordinates + 1 temporal) universe where we live. Hence, the Brane contains the 4 dimensions of our universe. Outside the Brane is the hyperspace, that he calls the **Volume**, which is space of more dimensions where the Brane is embedded. It is worthwhile to point out that hyperspace (the Volume) is a hypothetical space, it does not exist, but is useful for the understanding of the phenomena that occur in the Brane.

Figure 2 illustrates the case described above. The four-dimensional Brane is represented by a surface. The WH connects two points of the Brane by a shortcut through the Volume. In the guava example of figure 1, the guava peel is the Brane and its pulp is the inside Volume and the region exterior to the guava is the outside Volume. The hole of the worm may be considered as an alteration of the topology — i.e., of the shape — of the peel, being, therefore, an extension of the Brane that traverse the inside Volume.

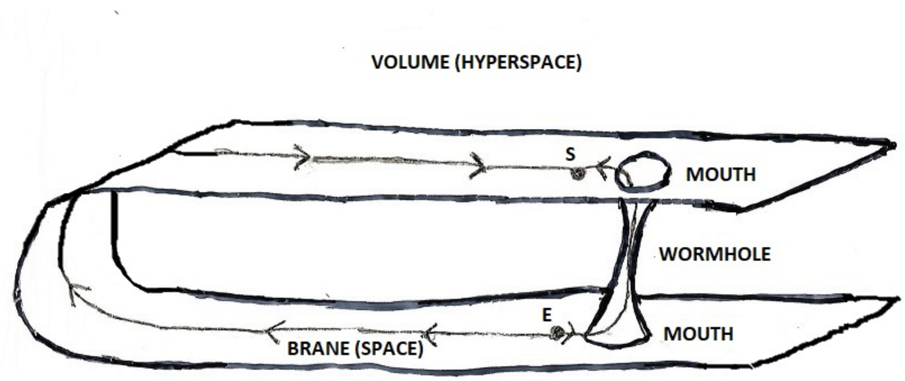

Figure 2: The interstellar voyager can go from Earth (E) to the star S by the two ways shown in the figure. The "wormhole" through the Volume (hyperspace) represents the shortest. The Brane entry and exit regions are called "mouths" of the WH.

The important issue is that since the discovery of the WHs it was verified that they are unstable. After being created they are quickly destroyed by the shrinking of their walls. And the contraction of the walls is so rapid that not even a light ray is able to travel the path from mouth to mouth. Here comes then the ScD. The shrinking of the WH can be avoided if there exists in its interior a reservoir of "negative energy" which would exert pression against the gravitational contraction. Is that possible? Yes, but the substance that has such a negative energy is yet to be found. It might be similar to the dark energy of the Standard Model of Cosmology (the Hot Big Bang model, cf. [4]), which exerts the cosmic pression that resists the decelerating gravitational pression and makes the expansion of the universe accelerated from recent epochs onwards. Everything is possible, but it requires an high dose of ScD, with frequent references to the putative theory of QG.

What about TMs? The TMs can be WHs (amongst other curious ScDs, which I shall not treat here). Now, due to the fact that WHs connect two spacetime events of the universe, they can very well connect two points of space, one of them being in the present and the other in the past. That is, one may go into a WM mouth in the present and come out the other one in the past. Of course, if one could avoid the contraction of the WH, which a highly advanced civilization would be able to do. The problem is that in addition to the technological limitations *there may be* a natural limitation, which I shall refer to below, through Kip Thorne's words.

2.2 Black holes

The black hole is a singular theoretical object that appears in one of the solutions of the GRT field equation, namely, the Schwarzschild solution (cf. section 15.2 of [5]). The Schwarzschild solution gives the spacetime structure in the exterior of a spherical body that does not rotate. The BH is a *singularity* of this solution. In theoretical physics, a singularity is something that does not exist, neither in nature nor in the formal conception of the theory, ultimately, is the collapse of a theory. In physics jargon, one says that that the solution "explodes" when it encounters a singularity. In general, in a singularity the solution tends to an infinite value. That is what happens with Schwarzschild solution. It explodes in the so-called *Schwarzschild radius*, which is given by:

$$R_S = \frac{2GM}{c^2},$$

where M is the body mass, G is the universal gravitation constant and c is the speed of light in vacuum. A BH is characterized by the so-called *event horizon* — or simply *horizon* — which is a spherical surface of radius R_S. Classically, i.e., outside the QG domain, the BH is a body of mass M that occupies a spherical region of radius R_S, in spite of the fact that the solution is not defined at $R = R_S$.

Figure 3 shows the singularity called BH. The question mark indicates that for $R \leq R_S$ the Schwarzschild solution is unknown, or more precisely, does not exist.

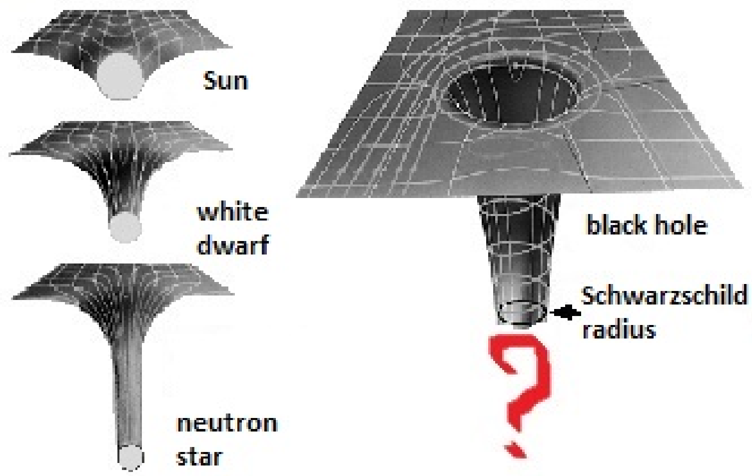

Figure 3: GRT shows that space — more precisely, space-time — curves near any body. It is as space behaves like a rubber sheet that is warped by the bodies sitting on it. Above one sees the warping of space around the Sun, a white-dwarf star, a neutron star and a black hole. The black hole makes a "bottomless pit" in space, or in other words, a hole whose bottom is completely unknown.

Space around the black hole is well-defined only for $R > R_S$, where R_S, the *Schwarzschild radius*, is shown in the figure. The question mark draws attention to this fact. The representations shown above are two-dimensional analogies of three-dimensional space realities. Try to imagine the latter.

The Schwarzschild radius can be written in terms of the Sun mass as $R_S = 3(M/M_{Sun})$ km. That is, a BH with the mass M equal to the Sun mass will have $R_S = 3$ km and its event horizon will be the spherical surface of 3 km of radius.

Strictly speaking, all scientific research about BHs belongs to the realm of the purest ScD. Incidentally, contrary to what is frequently stated, the singularity is not inside the event horizon; *the singularity is the event horizon*, located at $R = R_S$. For those interested in the subject, [3, chap. 3] is the finest piece of black-hole ScD.

3 Kip Thorne speaks up

Let's move now to Kip Thorne's labor with respect to the ScDs presented in section 2. First, I show excerpts about WHs and TMs and next those related to BHs.

> We can imagine two strategies for constructing a wormhole where before there was none: a *quantum strategy*, and a *classical strategy*. The quantum strategy relies on *gravitational vacuum fluctuations*, the gravitational analogue of the electromagnetic vacuum fluctuations. . .
>
> In 1955, John Wheeler, by combining the laws of quantum mechanics and the laws of general relativity in a tentative and crude way, deduced that in a region the size of the *Planck-Wheeler length*, 1.62×10^{-33} centimeter or smaller, the vacuum fluctuations are so huge that space as we know it "boils" and becomes a froth of quantum foam — the same sort of quantum foam as makes up the core of a spacetime singularity [3, p. 494].

Notice that this is the same quantum foam that is believed to reside inside of a black-hole singularity (cf. [3, p. 478]).

> We do *not* understand the laws of quantum gravity well enough to deduce, in 1993, whether the quantum construction of wormholes is possible. We *do* understand the laws of classical gravity (general relativity) well enough to know that the classical construction of wormholes is permitted only if the construction machinery, whatever it might be, twists time up so strongly, as seen in all reference frames, that it produces, at least briefly, a time machine [3, p. 498].

Kip Thorne's book [3] was written in 1993, which explains mentioning the year; the issue related to QG remains the same nowadays. "Twisting time" seems something weird, but it is worthwhile recalling that in GRT "twisted time" is one of the names of "gravitation". The matter-energy content of the universe and their pressure twist time and space, being this the way GRT describes gravitational effects, which are described in another way by Newtonian theory.

> The laws of general relativity predict, unequivocally, the flow of time at the two mouths [of the WH], and they predict, unequivocally, that

> the two time flows will be *the same* when compared through the wormhole, but will be *different* when compared outside the wormhole. Time, in this sense, hooks up to itself differently through the wormhole than through the external Universe, when the two mouths are moving relative to each other.
>
> And this difference of hookup, I then realized, implies that *from a single wormhole, an infinitely advanced civilization can make a time machine* [3, p. 502].

The TM requires, therefore, an *infinitely advanced civilization*. The TM is also closely related to a *Time Warp* (the *Time Warp* of [3]), i.e., to a different perception of the flow of time from different frames of reference.

The English theoretical physicist Stephen Hawking believes that TMs are impossible to exist in nature. In the absence of a QG theory he cannot proof his belief — his ScD —, then he put forward a conjecture about the issue. The following are Kip Thorne's words about it.

> Hawking has a firm opinion on time machines. He thinks that nature abhors them, and he has embodied that abhorrence in a conjecture, the *chronology protection* conjecture, which says that *the laws of physics do not allow time machines* [3, p. 521].

If some day, the conjecture can be proved, even an infinitely advanced civilization will not be able to build a time machine. Perhaps Hawking is right and for this reason until now, as it seems, we did not receive the visit of a inhabitant of the future.

Kip Thorne is so convinced of the urgent need of a QG theory that he makes mistakes when writes about Einstein's aspirations for an unified physical theory. Let us read:

> Albert Einstein spent most of his last twenty-five years in a fruitless quest to unify his general relativistic laws of physics with Maxwell's laws of electromagnetism; he did not know that the most important unification is with quantum mechanics. He died in Princeton, New Jersey, in 1955 at the age of seventy-six [3, p. 525].

Kip Thorne errs here. The desired unification is much ampler and Einstein certainly knew that. Long before 1955 there were already works on the unification of electromagnetism and quantum mechanics, which would result in quantum electrodynamics. The unification of quantum electrodynamics with the weak nuclear interaction was underway and would be crowned with the 1979 Nobel prize to its developers, whom have created the "theory of the electroweak interaction". There was in addition the strong nuclear interaction, that was not unknown to Einstein. In other words, the unification project is much more than the one depicted by Thorne and attributed to Einstein.

About Karl Schwarzschild, whose particular solution of Einstein's field equation led to the idea of BH, Kip Thorne states:

> The first step (after the inaugural presentation of GRT in 1915 [6]) was made by Karl Schwarzschild, one of the most distinguished astrophysicists of the early twentieth century.
> (...)
> Almost immediately he set out to discover what predictions Einstein's new gravitation laws might make about stars. Since it would be very complicated, mathematically, to analyze a star that spins or is nonspherical, Schwarzschild confined himself to stars that do not spin tat all and that are precisely spherical, and to ease his calculations, he sought first a mathematical description of the star's exterior and delayed its interior until later.
> (...)
> His calculation was elegant and beautiful, and the curved spacetime geometry that it predicted, the *Schwarzschild geometry* as it soon came to be known, was destined to have enormous impact on our understanding of gravity and the Universe [3, p. 124].

The BH is, as mentioned above, a singularity of Schwarzschild's geometry, and was known as "Schwarzschild's singularity" during a long time. The singularity has had other names, until the name coined by John Wheeler ended up prevailing. Schwarzschild's solution represents the greater — if not, so far, the only — contribution of GRT to gravitation. It possesses several applications of real success like, for example, in the calculation of the dynamics of planetary systems (amongst these, the solar system), in the calculation of the deflection of light by a given body and in the development of technologies of localization by satellites like GPS (*Global Positioning System*). The BH is a ScD of the Schwarzschild solution. Gravitational waves and other extreme gravitational phenomena are out of the scope of Schwarzschild's solution, but belong to the most genuine ScDs, some of them for requiring extremely sensitive and special detectors being, therefore, not observed, and others for waiting "a complete theory of QG". Schwarzschild's solution does not wait for anything and has practical applications of high experimental accuracy. The enormous scientific consideration enjoyed by GRT comes precisely from the solution found by Karl Schwarzschild in 1916 (cf. stressed in [6]).

Einstein himself did not like Schwarzschild's singularity:

> "The essential result of this investigation," Albert Einstein wrote in a technical paper in 1939 [7], "is a clear understanding as to why the 'Schwarzschild singularities' do not exist in physical reality." With these words, Einstein made clear and unequivocal his rejection of his own intellectual legacy: the black holes that his general relativistic laws of gravity seemed to be predicting [3, p. 121].

The above-mentioned Einstein's quotation is in the penultimate paragraph of the 15 pages of the 1939 article and the last one has the following words (boldface added): *"This investigation arose out of discussions the author conducted with Professor H. P. Robertson and with Drs. V. Bargmann and P. Bergmann* ***on the mathematical and physical significance of the Schwarzschild singularity****. The problem quite naturally leads to the question,* ***answered by this paper in the negative****, as to whether physical models are capable of exhibiting such a singularity."*

Contrary to what is often stated, BHs are still pieces of ScD. Rigorously, they do not exist, but represent unknown limits of known physics. Kip Thorne validates this judgement in many places of his book [3].

4 Final remarks

The recurring mention of the need of a theory of **Quantum Gravity** highlights the factual precarity of the ScDs mentioned here. They are clear examples of the concept of ScD, i.e., fiction coupled to educated speculation, the latter frequently anchored in the possibility of a QG in the future.

In this short inventory of relativistic holes certainly someone might have missed **white holes**. These may be thought as "time-reversed" black holes, that is, their physical processes occur in a way that is reversed to the way they occur in BHs. For example, matter and radiation emerge from a white hole with high energy. This ScD was popular in the decade of 1970, according to the English cosmologist Edward Harrison (1919-2007), and the idea seems not sustainable any more, as he mentions in passing in the chapter about BHs of his *Cosmology, The Science of the Universe* (2000). The white hole was a ScD that did not hold water. Incidentally, there is no mention whatsoever about white holes in [3].

Metaphorically, relativistic holes constitute true "holes" in the formal structure of GRT. According to many, Kip Thorne amongst them, such holes only will be plugged when we have a repairing theory of QG.

Kip Thorne, with his book [3], was our main reference in the discussion of relativistic holes. The quality of [3] as work of scientific **dissemination** may be questioned, but certainly one has there one of best compendiums of science **digression**.

References

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[3] K. Thorne, *Black Holes and Time Warps: Einstein's Outrageous Legacy* (W.W. Norton & Company, New York, 1994)

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