

## The black hole fifty years after: Genesis of the name

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Black holes are extreme spacetime deformations where even light is imprisoned. There is an extensive astrophysical evidence for the real and abundant existence of these prisons of matter and light in the Universe. Mathematically, black holes are described by solutions of the field equations of the theory of general relativity, the first of which was published in 1916 by Karl Schwarzschild. Another highly relevant solution, representing a rotating black hole, was found by Roy Kerr in 1963. It was only much after the publication of the Schwarzschild solution, however, that the term black hole was employed to describe these objects. Who invented it? Conventional wisdom attributes the origin of the term to the prominent North American physicist John Wheeler who first adopted it in a general audience article published in 1968. This, however, is just one side of a story that begins two hundred years before in an Indian prison colloquially known as the Black Hole of Calcutta. Robert Dicke, also a distinguished physicist and colleague of Wheeler at Princeton University, aware of the prison's tragedy began, around 1960, to compare gravitationally completely collapsed stars to the black hole of Calcutta. The whole account thus suggests reconsidering who indeed coined the name black hole and commends acknowledging its definitive birth to a partnership between Wheeler and Dicke.

## I. INTRODUCTION

Einstein's general relativity, finalized in 1915, is a theory of space, time and matter. Gravitation is explained by means of the spacetime curvature and its interaction with matter. As John Wheeler put it, spacetime tells matter how to move and matter tells spacetime how to curve [1, 2].

Black holes are objects predicted by general relativity. Since they are made solely of curved space and time, and energy, they are the most elementary objects of the theory. Stated in a simple form, black holes are regions from which no physical body, not even light, can escape. The boundary limiting this region is called the event horizon. The spacetime deformation caused by a black hole challenges our intuition. For instance, time flows arbitrarily slow in the neighborhood of a black hole. Another example: for a rotating black hole space is inexorably dragged by its rotation, making it impossible to stay still, even outside of the black hole.

The first mathematically exact solution of Einstein's theory of gravitation was the Schwarzschild solution [3], found in 1916 by the German astronomer and physicist Karl Schwarzschild. Schwarzschild wanted to explain the gravitational field outside a spherical star with this solution. However, considered as a complete solution without a central star, an intrinsic radius, called the gravitational or Schwarzschild radius, pops out clearly from the solution. This radius is very small relatively to the star's radius and so it would not make part of the solution with a central star. Moreover, the properties of the region it limits seem odd. Consequently, this seemingly irrelevant region for astrophysical considerations, which, additionally, is physically hard to grasp, was for a long time largely ignored by physicists.

Yet, in 1939, a remarkable theoretical work by Oppenheimer and Snyder [4] showed that the collapse of a star is complete, in its own frame of reference, with the star and its surface passing through the Schwarzschild radius without any resistance, continuing their inexorable collapse. This paper was crucial towards a physical understanding of the Schwarzschild solution that eventually surfaced in the late 1950s, with the works of Wheeler, Kruskal and others [1]. It then became clear that the gravitational radius yields a surface named event horizon and that the region inside the event horizon has interesting and peculiar properties.

The definite incentive to study these objects stemmed from the detection, in the early 1960s, of radio sources of tremendous energy. The additional discovery of an optical partner for these radio sources led to the conclusion that these sources had a recession speed of around 40% of the speed of light, thus suggesting that they were at cosmological distances, emitting a colossal amount of energy. These sources became known as quasars, short for quasi-stellar objects, because they looked like stars in the photographic plates [5]. The release of massive amounts of energy led to the speculation that highly compact objects, so compact that they could even possess an event horizon, were at the source of these phenomena and that relativistic processes were fundamental to generate these energies.

A period of important new discoveries, both theoretical and observational, followed. In 1963, Roy Kerr, a New Zealand physicist working at the University of Austin, Texas, discovered the exact solution for a vacuum rotating object in general relativity [6]. If, in the Kerr solution, the rotation is put to zero, the Schwarzschild solution is retrieved. The impact that both the Schwarzschild and the Kerr solution had in physics and astrophysics was such, that the solutions and the objects they represent needed to be named. It was Wheeler that, in an article in 1968, named these objects black holes [7]. The vacuum Schwarzschild and Kerr solutions were thereafter called Schwarzschild and Kerr black holes, respectively.

Concomitantly, astronomical observations over the last half-century established the physical reality of these objects, that appear to exist abundantly in the Universe. They result from the exhaustion of fuel in massive stars, which then collapse under their own weight [8]. Additionally, supermassive black holes are known to exist at the center of all, or almost all, galaxies and were formed in the early stages of the Universe. Our own galaxy, the Milky Way, has a supermassive black hole at its center, with about 4 million solar masses [9]. In 2015, the spectacular detection of gravitational waves by the LIGO antennae [10] confirmed the existence of black holes in a completely new manner, revealing a previously inaccessible population.

It is interesting to speculate whether Einstein could have reached, beyond the dark stars of Mitchell and Laplace, the black hole and event horizon concepts back in 1905, solely based in Newton's gravitation and the notion, from special relativity, that the speed of light is both unsurpassable and a universal constant [11]. Einstein, however, was never interested

in either stars or in black holes. In any case, the time was not ripe for this concept to appear spontaneously, as history would show. Even after the theory of general relativity being formulated and finalized, the path to reach the concept of black holes and to grasp the significance of these objects in their physical and mathematical plenitude would still prove strenuous and convoluted [12, 13].

The science of black holes is magnificent and the interest in these objects has certainly entered the imagination and imaginary of human culture. As such, it is only natural to ponder on the history of these objects, starting with the simple questions of where and how the term black hole originated. As we will see, there is an aura of mystery and a fascinating story.

## II. THE INITIAL NAMES

The first physicists to dwell on the Schwarzschild solution believed that at the Schwarzschild radius the gravitational field would be infinite and thus spacetime appeared pathological in this region. Hence, the Schwarzschild radius was also known as the Schwarzschild singularity [14]. However, with the 1939 work of Oppenheimer and Snyder it became clear that there was nothing singular at that radius and so Schwarzschild singularity was an inadequate terminology that did not faithfully represent the spacetime character of the region.

In the 1960s, Soviet Union physicists, notably Yakov Zel'dovich and Igor Novikov, put forth the term frozen star to describe this object [15]. This designation reflected the fact that for an external far away observer, the star seems to be frozen when it reaches the Schwarzschild radius, see [16] for a modern version of a frozen star. On the other hand, American physicists, namely Wheeler, and European physicists like Roger Penrose and others, applied the terminology collapsed star [17]. This name emphasized the complete collapse of the star into a true curvature singularity in its own frame.

But none of the names was a good name and Wheeler knew it. As to correctly convey the physics and processes involved, a suitable name is essential. In 1958, Wheeler proposed the term wormhole to describe shapes that connected different regions, yielding spacetimes with nontrivial topology. Ten years later he named collapsed objects as black holes.

### III. JOHN WHEELER'S VERSION FOR THE TERM BLACK HOLE

John Wheeler, in chapter 13 of his scientific autobiography *Geons, Black Holes & Quantum Foam*, with subtitle *A Life in Physics* [18], see Figure 1, explains how the term black hole was introduced to describe the final state of a collapsing massive star.

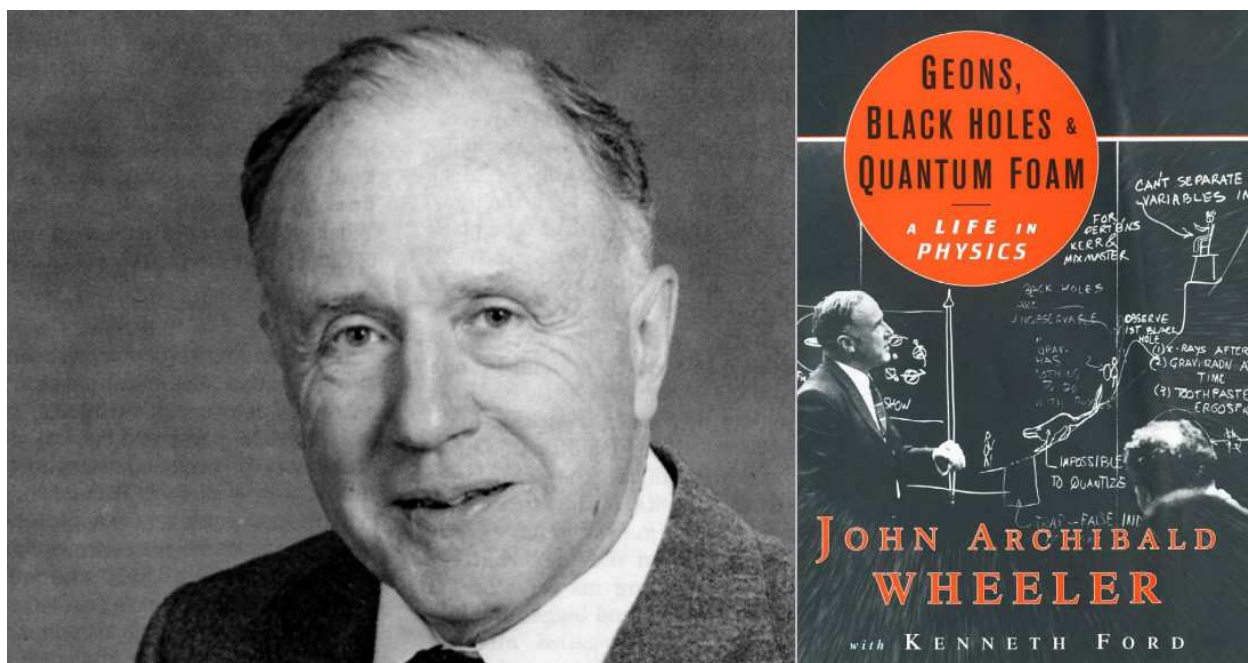


FIG. 1: The physicist John Archibald Wheeler (1911-2008) and his scientific autobiography [18].

Wheeler, a physicist from the University of Princeton, excelled as a nuclear physicist in his early career. He invented the S-matrix which accounts for the quantum scattering of particle collisions and participated in the Manhattan project that developed the first nuclear weapon. In his autobiography, Wheeler describes how his interest in nuclear physics and, subsequently in general relativity, led him in the 1950s to turn his enthusiasm towards the study of stars and, more specifically, to the stars' centers at the end of their lives. What is the final state of a star after having exhausted all its nuclear fuel? Does it explode? Or does it implode into a dense core of nuclear matter? These were just some of the questions Wheeler wanted to find the answer to. He was not the first to ask them and partial answers already existed. It was known that the fate of a star depended on how massive it was.

Low mass stars could end their lives as white dwarfs as suggested by Subrahmanyan Chandrasekhar, an Indian physicist working at Cambridge, around 1930. The Chandrasekhar limit is the maximum mass a white dwarf can have, which is 1.4 times the mass of the sun. Following the ideas of Fritz Zwicky, a Swiss astronomer settled at Caltech, there were speculations that stars with higher masses could end their lives as neutron stars. These stars had not yet been observed but were theoretically predicted as highly compact bodies in which extreme gravitational forces oblige the existing electrons and protons to merge into neutrons. The star becomes a sort of giant atomic nucleus and, as Landau, the renowned Russian physicist deduced, the value of a neutron star mass limit was of the order of the Chandrasekhar limit. Oppenheimer and Volkoff in 1939 confirmed Landau's prediction for the neutron star maximum mass and they noted that it was theoretically possible that nothing could stop the implosion of an even more massive star. In turn, Oppenheimer and Snyder, still in 1939, through a simplified model, presented the famous result that a star could collapse to the inside of its own gravitational radius [4]. Later, in the 1950s, these problems were reconsidered by Wheeler and his students. They showed that within a certain mass interval, which they found to be slightly superior to the Chandrasekhar limit, neutron stars could be stable and describe the final state of the collapse of a star. However, it was the fate of the most massive stars that intrigued Wheeler. After initial hesitations, he ultimately accepted the generic validity of Oppenheimer and Snyder's result. For extremely massive stars their final state was one of a gravitationally completely collapsed object (see [12, 13] for a detailed explanation).

As Wheeler writes in his autobiography, after a decade considering these ideas, in the fall of 1967, he was invited by Vittorio Canuto from the NASA Goddard Institute in New York to attend a conference about the nature of a new astronomical body, the pulsar. The pulsar had been discovered a few months earlier by Jocelyn Bell Burnell and Antony Hewish at Cambridge. It would soon be confirmed that pulsars are rotating neutron stars. In his lecture in New York, Wheeler argued the possibility that at the center of a pulsar there could be a "gravitationally completely collapsed object". This terminology, however, was long and inconvenient and Wheeler commented in his lecture that he could not be repeating it all the time and a shorter version was needed. At that moment, someone in the audience suggested,

“How about black hole?”. Wheeler writes that he found the term perfectly appropriate for a “gravitationally completely collapsed object”, terminology which he had been searching for months. A few weeks later, on December 29th 1967, Wheeler was invited to give a talk, the Sigma Xi-Phi Beta Kappa lecture entitled “Space and Time”, at the annual meeting of the American Association for the Advancement of Science in the New York Hilton [19]. There, he employed the term black hole, which was then included in the written version of the lecture, published in the spring of 1968 [7]. As such, according to Wheeler, the name black hole entered the scientific literature.

Bartusiak, a distinguished physics and astrophysics writer, confronts Wheeler’s memories [20]. Actually, the conference on pulsars and neutron stars at the Goddard Institute, only took place in May 1968; pulsars had been official announced in February of the same year. In November 1967, there was in fact a conference about supernovas at the Goddard Institute, but Wheeler’s name is not in the proceedings of the conference [21]. It is possible that he gave a lecture at this meeting and did not send the written version to the editors; however even this is not certain. What is irrefutable is that he uttered the term black hole in the after-dinner speech at the annual meeting of the American Association for the Advancement of Science and that the term was printed in the American Scientist journal in 1968 in an article entitled “Our Universe: The Known and the Unknown” [7]. Moreover, there is no doubt that with this publication the name black hole was adopted worldwide and it became common usage throughout all the sphere of knowledge, with Wheeler at its origin.

#### **IV. THE TEXAS SYMPOSIUM IN DALLAS AND THE MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE IN CLEVELAND IN 1963**

Irrespective of the details of Wheeler’s tale on the origins of the term black hole, there is a story he did not tell.

This story dates back to a scientific meeting that took place in Dallas, in July 1963, the Texas Symposium on Relativistic Astrophysics. The planning of this event had been motivated by the recent discovery of quasars, the objects located at cosmological distances

that emitted colossal amounts of energy. In fact, part of the scientific community began to speculate that relativistic phenomena and concepts played an important role in explaining the generation of these energies, sparking, in turn, the idea to hold a conference on relativistic astrophysics [22, 23], a scientific field inexistent at the time.

Astoundingly, the term black hole was presented in the first Texas Symposium, when discussing gravitationally completely collapsed objects, a concept that scientists attending the meeting attempted to relate with the huge amounts of energy emitted by quasars.

In the aftermath of the Symposium, Life magazine published an article by Albert Rosenfeld, in the beginning of 1964, entitled “Heavens’ new enigma, What are quasi-stellars?” [24]. The article refers to the Dallas encounter that had been held six months before and is focused on quasars. It presents the idea, due to the astrophysicists Fred Hoyle and William Fowler, that the energy source of quasars could be linked to the gravitational collapse of matter, which in Rosenfeld’s words, would then result in an “invisible black hole in the universe” [24].

The term was maintained in another conference in Cleveland, in December of 1963, promoted by the American Association for the Advancement of Science. This conference prompted journalist Ann Ewing to write an article named “Black Holes in Space” [25], see Figure 2. The journalist starts the article with the statement “Space may be peppered with black holes”, followed by “Such a star then forms a “black hole” in the universe”. This article is the first time the term black hole appeared in print. Rosenfeld’s article on the Texas Symposium, held in July of the previous year, was published with delay, six days after Ewing’s article.

SCIENCE NEWS LETTER *for January 18, 1964*

ASTRONOMY

## **"Black Holes" in Space**

**The heavy densely packed dying stars that speckle space may help determine how matter behaves when enclosed in its own gravitational field—By Ann Ewing**

FIG. 2: Ann Ewing’s article in 1964 where the term Black Hole is published for the first time [25].



Both authors, Rosenfeld [24] and Ewing [25], published the term black hole with the same meaning as Wheeler but four years before Wheeler’s article [7]. It is known that they did not create the term. Marcia Bartusiak, states that Rosenfeld himself said that he did not invent the term, he simply heard it named in the Dallas meeting [20]. Notwithstanding, neither Rosenfeld nor Ewing clarified which physicist or physicists utilized the term in Dallas and Cleveland.

## V. ROBERT DICKE AND THE BLACK HOLE OF CALCUTTA

The first Texas Symposium was so successful that it originated a conference series, with the same name, held every two years. In the twenty seventh Texas Symposium, in 2013, Bartusiak presented her paper on the origin of the term black hole [26] (see also [20]). Hong-Yee Chiu, an American astrophysicist of Chinese origin that had invented the term quasar [5] and had actively participated in the first Texas Symposium in Dallas, besides organizing the meeting in Cleveland, confirmed that he had quoted the name black hole in that meeting. In fact, the phrase “Space may be peppered with black holes”, with which Ewing starts off her article, is attributed to him. However, Chiu denied having invented the term black hole and traced its origin to a colloquium he was present in 1960 or 1961, as a postdoc, delivered by Robert Dicke, see Figure 3. At the colloquium, Dicke compared gravitationally completely collapsed stars to the “black hole of Calcutta”. According to Chiu [20], the term black hole was repeated by Dicke in his lectures in 1961 and 1962 in the New York Goddard Institute, where Chiu now worked. These lectures, that were part of a series of lectures given also by other speakers including Wheeler, have been documented [27] but the term black hole is not alluded to in the proceedings.

Additionally, Martin McHugh, a physicist interested in Dicke’s work, told Bartusiak [20] a different and curious perspective on the subject, see also [28] for other details. Robert Dicke’s children remember their father saying “Ah, it must have been sucked into the black hole of Calcutta” whenever something got lost at their house. What is the black hole of Calcutta Dicke is referring to? There was a place named the black hole of Calcutta, sadly

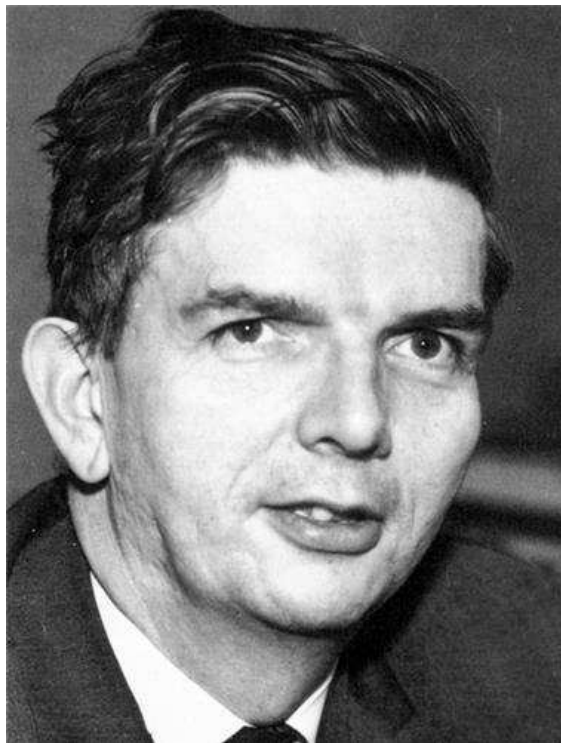


FIG. 3: The physicist Robert Dicke (1916-1997).

famous in the history of British India. It was a small prison, in Calcutta's Fort William, destined to no more than two or three prisoners at a time. Following a dispute with the East India Company, which controlled Fort William in the 18th century, the local governor Siraj ud-Daulah, order a siege of the Fort, which was ultimately conquered on June 20th, 1756. In John Howell's account of the episode, 146 soldiers of the East India Company were captured. The conquerors confined the captives to the small prison in the Fort, known as "black hole" in the jargon of the soldiers. The cell was so overcrowded that it was hard to shut the door. During that night, 123 of the 146 prisoners were suffocated or crushed to death. The details of the incident are debated by other sources, but this version was perpetuated during Britain's rule over India. There is even a monument to the tragedy in St. John's church in Calcutta, in memory of those who "perished in the Black Hole prison" [29]. This account, of more than hundred men being crushed in a small space named black hole, inspired Dicke to give that same name to an object resulting from the total gravitational collapse of a star.

Thus, the term black hole appeared firstly through Robert Dicke.

## VI. THE PLAUSIBLE STORY BEHIND THE NAME BLACK HOLE

The term black hole was commonly mentioned since at least 1961 in circles close to Wheeler. It thus seems odd why he omitted the previous usages of the term in his account of the origin of the name black hole, including the uses that appeared in print.

Canuto, the organizer of the meeting in the Goddard Institute in 1967 that actually took place in 1968, showed discomfort when confronted with Wheeler's version presented in the book. He even said, visibly uncomfortable, "Wheeler could have told the story he wanted" [30].

In fact, it is impossible that Wheeler and Dicke, as colleagues at Princeton, never touched upon the subject or that Wheeler never heard such an idiosyncratic expression as "black hole of Calcutta" in the Princeton corridors. Wheeler attended the lectures at the Goddard Institute in 1961 and 1962, where Chiu declared hearing Dicke utter the name black hole repeatedly. He was also at the 1963 Texas Symposium in Dallas, where the name black hole also appeared recurrently, the article corresponding to his presentation on gravitation theory and gravitational collapse appeared not in the proceedings, but as a separate book with his collaborators Harrison, Thorne, and Wakano [22]. It seems that Wheeler did not go to the meeting in Cleveland in that same year where the name was also spoken, but all in all by 1963 he had been in at least two places where the participants were talking freely about black holes already.

The name black hole did not fit well with some people. It was found to be obscene, or even slang. Feynman, for instance, accused Wheeler of being perverse for using this term [20]. For finding it improper, the French physicists resisted the adoption of the name for a long time, even when the name was already widely written and spoken [17]. Hence, it becomes clear that despite being accepted at Princeton and amongst its sphere of influence in the early 1960s, the term was not quite ready to be generally accepted. However, there was a day where there was no more embarrassment and obstacles were put aside forever.

What transpires is that at some point in the autumn of 1967, presumably in New York, Wheeler decided to adopt the name definitively, regardless of the other interpretations it might had, and used the story that someone in the audience shouted the term at him as a

metaphor for another reality.

This interpretation is reinforced by José Acácio de Barros, a Brazilian physicist from San Francisco State University, that collaborated with Patrick Suppes, a North American science philosopher. According to Barros, in a conversation between him, Suppes and Wheeler in 1996, Wheeler stated that the name black hole was recurrent in his conversations with Dicke, and that there were always playful smiles between the two when the name was brought up [31]. Moreover, in that same conversation, according to Barros, the person in the audience that screamed “How about black hole?” was Dicke himself [31, 32].

And thus, the circle closes. History, when analyzed in detail, is frequently richer than what it is portrayed by conventional wisdom. It is intriguing that John Wheeler suppressed, in his description of the origin of the term black hole, the former practices of this terminology. In the history of the term black hole it is factual that John Wheeler was neither the person who had the idea for the name nor the first one to publish it with its modern scientific meaning. It was Dicke that had that breakthrough and gave his consent to Wheeler by shouting “How about black hole?”, so that Wheeler could start using the name freely.

## **VII. THE ACCEPTANCE, POPULARITY AND IMPORTANCE OF THE NAME BLACK HOLE**

When Wheeler in 1968 named as black hole a subsection of his article [7], he gave his authority to the term, and the name black hole immediately captured the imagination of scientists and the public in general. Throughout the following fifty years, from 1968 to the present day, the name black hole was used an astronomical number of times and now, fifty years after, it is clearly a date to be celebrated [33].

It really is the ideal name. The singularity creates a hole in spacetime, preventing anything in the region within the event horizon to escape out from it. For an outside observer, this hole is black, since not even light emanates from it.

The 1916 Schwarzschild solution was initially considered as a solution that described the exterior spacetime of a star, see [34] for the celebration of the 100 years of the solution. However, when considered as a vacuum solution, without a star, it presented problems that

physicists struggled to solve. Only several decades after the solution was published and fully understood did it get its definitive name: Schwarzschild black hole. It is difficult to stress the extreme importance of the Kerr black hole, i.e., the solution of a rotating black hole. Astrophysical black holes have some degree of rotation, small or large, and the Kerr black hole solution allows the study of dynamic processes that mirror what is occurring in the neighborhood of an observed black hole. Moreover, by bringing new dynamics to black holes, the Kerr solution permitted new surprising theoretical developments. For example, one was able to prove that “black holes have no hair”, another term created by Wheeler in 1971 to clarify that black holes only had two properties: its mass and its angular momentum, see [35] for a modern discussion about this theorem. Initially, this term also prompted some controversy. Despite his serious sober temper, Wheeler had a naughty side to him, which was shown and confirmed by Thorne when he wrote that, by coining the term “black holes have no hair”, Wheeler generated a series of problems with the editor of the Physical Review [17], see also [36].

The extraordinary progress in black hole theory continued with the possibility of energy extraction from rotating black holes via superradiance and the Penrose process. It definitely culminated with the discovery that black holes are thermodynamic bodies and with Hawking’s 1974 breakthrough that, via quantum processes, they emanate radiation with black body temperature. But that is another story.

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