Black Hole

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Black holes are the celestial objects existing at the center of every galaxy. They can currently only be described by their spin, charge, and angular momentum, with other attributes derived from the basic properties. The existence of black holes was first predicted by German physicist and astronomer Karl Schwarzschild in 1916, with the exact solutions to Einstein's field equations of general relativity one year after its publication. Finnish physicist Gunnar Nordström proposed a theory of gravity and electromagnetism with four spatial dimensions in 1914, and later developed into the stationary charged black hole in 1918.

black hole | general relativity | active galactic nuclei

1. History

The existence of black holes was predicted by German physicist and astronomer Karl Schwarzschild in 1916, with the exact solution to the Einstein field equations of general relativity [1]. The non-charged stationary Schwarzschild black hole became the main subject of interest for the leading Manhattan Project scientists, such as J. Robert Oppenheimer and John A. Wheeler, a decade later [2][3]. John A. Wheeler coined the term "black hole" and furthered the Schwarzschild Radius defining the event horizon of Schwarzschild black holes to the singularity [3][4]. Differentiated from the Einstein-Rosen Bridge approach to Schwarzschild wormholes that discover the dimensions of space, J. Robert Oppenheimer turned to the nuclear stability of fusion cores with the presumptions of neutrons, and published the paper with George Volkoff in 1939, proving neutron cores, like white dwarfs, could not be indefinitely heavy [5][6][2].

German aeronautical engineer and mathematical physicist Hans Reissner and Finnish physicist Gunnar Nordström, respectively in 1916 and 1918, put forth the black hole with mass and charge [7][8]; the non-stationary solution to general relativity was not derived until 1963 by Roy Patrick Kerr, defining the space outside a rotating black hole [1][9]. In 1965, American physicist Ezra T. Newman generalized the Kerr solution and found the axisymmetric solution to general relativity with the both rotating and electrically charged black hole [10]. The classical theoretic developments of black holes are thence completed with the physical properties listed in **Table 1** [11]:

Table 1. Types of Black Hole.

Name	Charge	Spin

Schwarzchild black hole	No	No
Kerr black hole	No	Yes
Kerr-Newman black hole	Yes	Yes
Reissner-Nordström black hole	Yes	No

2. Significance in Cosmology

Oppenheimer's proof reinforced the belief that black holes result from star collapse, following the explosion of large stars into supernovae, with the Big Bang cosmology ideated by Belgian physicist contemporary to Einstein's time, George Lemaître, and popularized by English astronomer Fred Hoyle on March 28, 1949 during a defense [12]. Therefore, solar mass (denoted by $m_{\odot}$) is usually adopted to describe the mass of a black hole. Two types of black holes are categorized in the Bang Bang model according to the origins, primordial black hole and the normative black hole from stellar remnants. Primordial black holes are thought to be created not soon after the Big Bang, and the black holes from stellar remnants are thought to be created after a star exhausted its capacities for nuclear fusion [2]. It is estimated that for a star to be capable of compaction into a singularity, it must have a mass greater than 3.4 times that of the Sun.

The paradigmatic questioning into the Big Bang interpretations was marked by British mathematical physicist and astronomer Roger Penrose's attributions in 1963 to the asymptotic properties to the space-time continuum [13]. It was calculated by Steven Weinberg in 1981 that the time required for a proton to decay would far surpass the age of the universe calculated by the Big Bang model, having a lifetime at least 10^{20} times of the latter [14]. Roger Penrose sought to reconcile the Big Bang model with the particle physics advancements and proposed the "Before the Big Bang" insights in 2006 and Conformal Cyclic Cosmology later [15][16][17]. Black hole astrophysics thus signify the threshold of our current understandings of the universe.

3. Application

The application of black hole physics on quantum mechanics emerged in the 1970s at the end of the Space Race. Cryogenic engineering was adopted to further the photometric method from Schwarzschild, and black hole thermodynamics became one of the main topic of interest [18]. The applications of black holes physics led to further empirical findings such as Hawking radiation with observations on the antimatter distribution around black holes [19]. It was once believed that Hawking radiation implies the eventual evaporation of black holes, but the idea was rejected by some physicists and later Hawking himself [20][21][22].

In observational astronomy, Bolometric luminosity (denoted by L_{Bol}) is applied to describe the black hole mass and accretion rate phenomenon with active galactic nuclei (AGN) [23]. With the large range of bolometric luminosities for a given black hole mass, Eddington limit is applied to define an approximate upper limit to the luminosity [24]. The absolute magnitude of black holes can be derived thanks to the findings of Hawking radiation, and low surface brightness galaxies also came into the vision of observational astronomers [25].

4. Scientific & Cultural Influences

The concept of black hole did not catch popular attention until Steven Hawking published his book *A Brief History of Time* in 1988. Its scientific influence, however, never faded since its conception by Einstein's general theory of relativity. Albeit it is unrealistic to circumvent black holes from nuclear weaponry, where Einstein's letter to Franklin D. Roosevelt saw to that, the critical and intensive development of the applied physics originated from the Manhattan Project scientists and with the NASA Deep Space Network [26][27][28]. The part of the black hole histories with nuclear weapons is put on stage by Christopher Nolan with the movie *Oppenheimer* in 2023 [29]. Also brought to popular culture by Nolan is wormholes in his artistic depictions in the 2014 movie *Interstellar* [30].

The more classical cultures swayed from the reflections of wars and nuclear weapons, characterized by Stanley Kubrick, and the movie *The Black Hole* directed by Gary Nelson screened in 1979 inspired the modern and contemporary cultures with George Lucas' *Star Wars* -- a return to the films first ever made with the space theater by Georges Méliès, A Trip to the Moon [31][32][33][34].

5. New Progress

With the facilitation of NASA Deep Space Network, the U.S.A.'s space-based telescope missions operate differently in concept with the European counterparts. The European Space Agency (ESA)'s missions, characterized by Planck Observatory, International Gamma-Ray Astrophysics Laboratory (INTEGRAL), XMM-Newton, etc., concentrate on cosmological observations, while the NASA missions focus more on the wavelength functionalities [35]. A list of space-based telescopes commissioned by the two major institutions is summarized in **Table 2**.

Table 2. List of Major Space-Based Telescopes

Year	Telescope	Institution	Wavelength	Objectives
1990	**Hubble Space Telescope**	NASA & ESA	Visible, UV, Near-IR	Deep Space Objects
1995	Solar & Heliospheric Observatory	NASA & ESA	Optical-UV, Magnetic	Sun and Solar Wind
1999	XMM-Newton	ESA	X-ray	Various
1999	Chandra X-ray Observatory	NASA	X-ray	Various
2002	INTEGRAL	ESA	Gamma ray, X-ray, Visible	Various

2003	Galaxy Evolution Explorer	NASA	UV	Galaxies
2003	Spitzer Space Telescope	NASA	IR	Distant and Nearby Objects
2004	Swift Gamma Ray Burst Explorer	NASA	Gamma ray, X-ray, UV, Visible	Various
2006	COROT	CNES & ESA	Visible	Extrasolar planets
2006	Solar Terrestrial Relations Observatory	NASA	Visible, UV, Radio	Sun and Coronal Mass Ejections
2008	Fermi Gamma-ray Space Telescope	NASA	Gamma-ray	Various
2009	Herschel Space Observatory	ESA & NASA	Far-IR	Various
2009	Planck Observatory	ESA	Microwave	Cosmic Microwave Background
2009	Kepler Mission	NASA	Visible	Extrasolar planets

The modern and contemporary progresses for black hole astrophysics have sprung up in the technological realm. The Laser Interferometer Gravitational-Wave Observatory (LIGO) was completed in 1999, with the first search for gravitational waves beginning 2002 and concluding in 2010 [36]. The sister facility Virgo began its construction in 1997 in the countryside near Pisa, in Italy, and the European Gravitational Observatory (EGO) was founded in 2000 [37]. Inaugurated in 2003, Virgo's scientific observations began in 2007, and an agreement to operate Virgo and the LIGO detectors, in the USA, as a 'single machine' was signed [38].

Contemporary Developments

Mainland China born cosmologist Yang I. Pachankis theorized that black holes are thermonuclear-binding to white holes, and derived data evidence from the NASA multi-wavelength space-based telescopes seen in **Figure 1** [39][40][41]. He interpreted the antimatter-saturated surface plasma interactions to be mediated by the fifth cosmic force, shifting between fusion and fission processes just as centromeres in DNAs do [42][43]. He asserts the formation of Hawking points is backlash from the black hole seed and white hole seed collision momentum, resulting from the asymptotic thermodynamics [11].

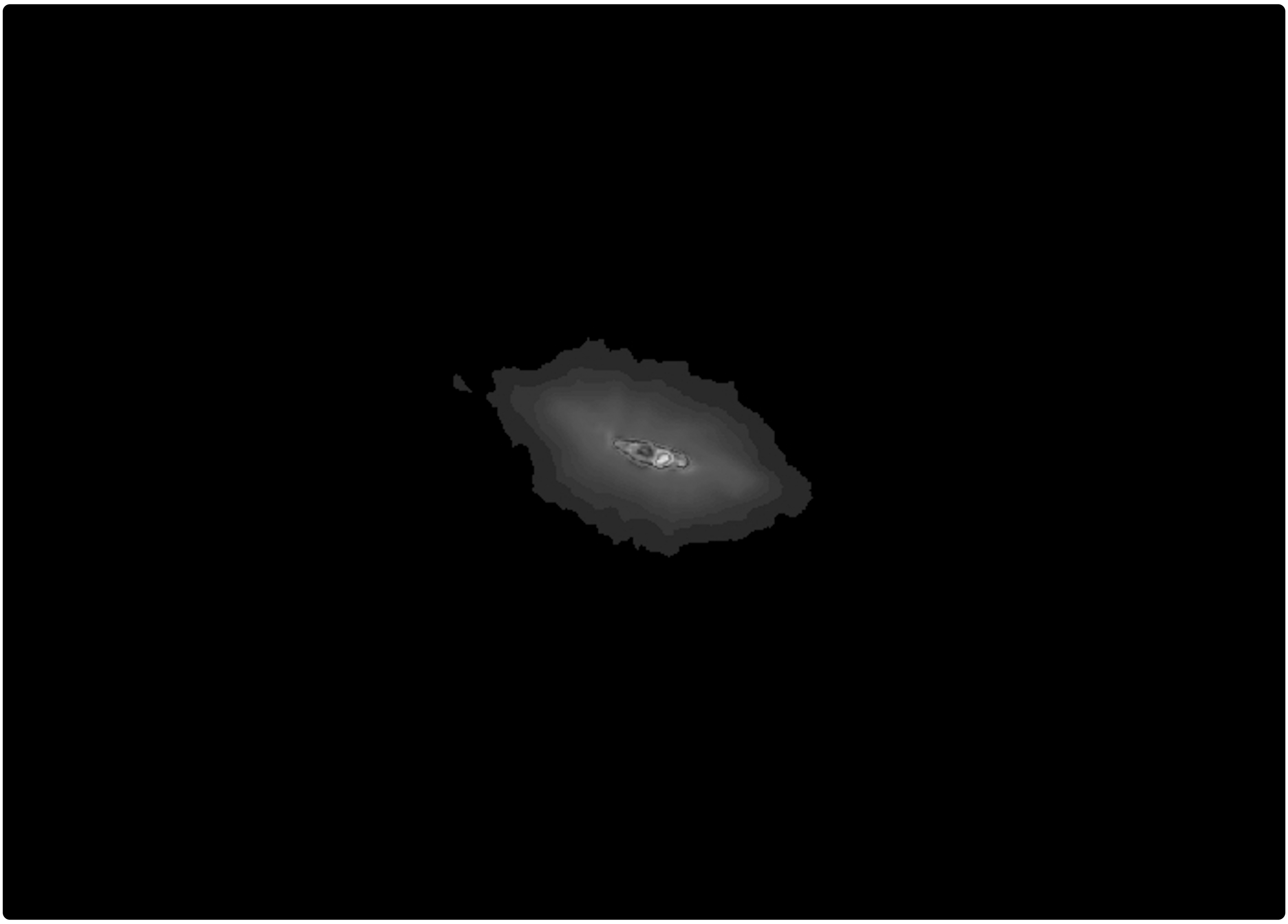

Figure 1. Surface recombination of NGC 3034 anti-matter plasma with neutron signature in the black hole portal and the white hole.

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