Studia Humana
Volume 10:1 (2021), pp. 1—4

A Short History of the Discovery of Black Holes

Martin Braddock

Sherwood Observatory, Mansfield and Sutton
Astronomical Society
Coxmoor Road, Sutton-in-Ashfield
Nottinghamshire, NG17 5LF
England, United Kingdom

Science4U.co.uk, Radcliffe-on-Trent
Nottinghamshire, NG12 2LA
England, United Kingdom

e-mail: martinbraddock@rocketmail.com

Abstract:
The concept of black holes or completely collapsed gravitational objects as they were originally called has fascinated the scientific community and writers of science fiction for centuries. The mathematical proof of the existence of black holes came from the collation of multiple lines of evidence, some of which were highly debated and was derived from both indirect and direct sources. The measurement of gravitational waves and the observation of a black hole represent one of the most astounding achievements in astrophysics which will open up new areas of investigation for the role that black holes play in the formation, maintenance and evolution of galactic structure.
Keywords: general relativity, Chandrasekhar limit, singularity, gravitational waves, black hole, galactic structure.

1. Introduction

Why should black holes exist and how do we *know* that they do? This article summarises some major developments over the last 236 years, which describe the theory and fact which shows that they *do* exist, celebrated by the ground-breaking publication of the first image of a black hole.

2. Early History

1784 – 1965: Establishing the Theory

In 1784, John Michell first suggested that objects could have such a high mass that light is unable to escape their gravitational field [1]. Albert Einstein's general theory of relativity in 1915 [2] described how mass could bend space and produce gravity, proposing that orbits of stars and collsions of massive accelerating objects, would cause ripples in the fabric of space – gravitational waves as we call them today.

Einstein's theory stimulated further thinking by Karl Schwarzschild [3] that a single spherical body – called a singularity – could be produced of infinte mass in a very small volume. The fate of stars when they run out of fuel depends upon their size and may produce either a white dwarf, a neutron star, or a black hole, with each object having increasing density. The term Chandrasekhar limit, proposed by Subrahmanyan Chandrasekhar in 1931 [4], is the maximum mass of a stable white dwarf star and white dwarfs with greater masses undergo further collapse to either neutron stars or black holes. Should massive stars collapse under the weight of their own gravity as proposed in 1939 [5], it was believed that the star would grow dimmer as it collapses.

That all large stars approximately 1.4 times the mass of the Sun (the Chandrasekhar limit) would form singularities was finally accepted in Sir Roger Penrose's 1965 publication [6], settling the theoretical problem of whether black holes *could* exist. These new bodies were originally called 'completely collapsed gravitational objects' and it is generally accepted that the term 'black hole' was coined by John Wheeler in 1967 [7].

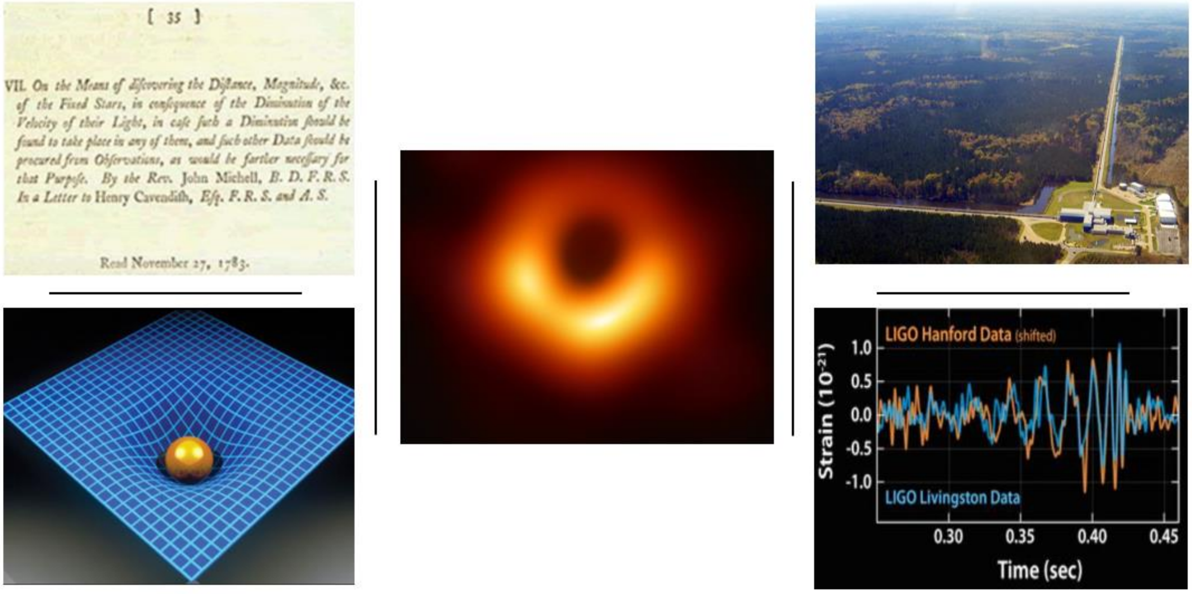
Further observations supporting the theory came from quasi-stellar objects (quasars) first discovered in the 1950s [8]. In 1964, Maarten Schmidt observed that quasar spectral lines of hydrogen were highly red-shifted, implying that quasars were either receding at a speed much greater than any known star or are highly luminous and compact objects [9]. We now know the latter to be the case and quasars are extremely luminous and active galactic 'powerhouses' emitting light from gas in a swirling disc surrounding supermassive black holes.

3. Later Years

1965 – 2015: Testing and Confirming the Theory

Evidence for the existence of black holes is both indirect and direct. Indirect evidence comes from the use of Kepler's equations to measure the mass of an object by its gravitational influence on other bodies, for example the stars that orbit it. The first black hole binary system called Cygnus-1, was identified as a bright point source of X-rays in 1965 [10] and the X-ray emission from it suggested a small collapsed object of approximately 15 times the mass of the Sun [11]. Later, an intense radio source called Sagittarius A* was discovered from an object very close to the centre of the Milky Way. When Kepler's equations were applied to the stars orbiting Sagittarius A*, the mass of the central object was estimated to be 4.4 million times the mass of the Sun. This suggested the existence of a massive black hole at the centre of our galaxy [12].

The first *direct* evidence of the existence of black holes came in 2015 with the observation of gravitational waves [13] by detectors at LIGO (<u>L</u>aser-<u>I</u>nterferometry <u>G</u>ravitational-Wave <u>O</u>bservatory). Like a water wave in the sea, gravitational waves squeeze and stretch the medium, in this case space and extremely small changes can be measured by 2 detector arms. Each arm is about 4 km long and there are 2 facilities 3000 km apart with a mirror at the end of each arm, a laser source and very sensitive instruments. The team found data consistent with the merger of two black holes of approximately 36 and 29 times the mass of the Sun. Since then, many gravitational wave events have been recorded.



Five key events in the history of black holes. *Michell's paper read in 1783 and published in 1784 (top left; credit Royal Society of London) sowed the idea and Einstein's theory of General Relativity published in 1915 predicted matter would distort the fabric of space (bottom left; credit Physics stack exchange). Fast forward 140 years to one of the two LIGO interferometers (top right; credit Caltech/MIT/LIGO lab) and a signal measuring gravitational waves (bottom right; credit LIGO) and the first image of a black hole (centre; credit Wikimedia Commons).*

2015 – The Present Day: 'Seeing' the First Black Hole

Further indirect evidence came from the detection of the event horizon – the point from which matter cannot escape the gravitational pull of a black hole – in the centre of the Messier 87 galaxy known as M87*. Three radiotelescopes measured the emission of high-energy photons and modelled the expected brightness observed for material either falling onto a surface, or through an event horizon. The study discovered that M87* was darker than would be expected for an object with a surface and concluded that scientists had actually witnessed the event horizon [14].

The first image of a black hole was published in 2019 [15]. Data was collected by the Event Horizon Telescope, a collection of 8 radio-observatories across 4 continents over 2 years and shows M87* to have an enormous mass of about 6.5 billion Suns – a truly supermassive black hole. The image resembles a circular void surrounded by a lopsided ring of light which shows the black hole as a silhouette. Further analysis of the imaging data shows the brightness flickering over time [16], which is likely due to M87* shredding and consuming nearby matter heated to billions of degrees as it gyrates through intense magnetic fields before it plunges over the event horizon and is finally consumed. Also in 2020, LIGO detected a strong gravitational wave signature consistent with the merger of two black holes of 85 and 66 times the mass of the Sun [17] – described by the one of the scientists on the team as 'mindboggling'! Recognition of the scientific theory and proof of the existence of black holes came to fruition with the award of the Nobel prize in Physics to three scientists, including Sir Roger Penrose in October 2020.

We have indeed come a very long way since 1783 and there is no doubt more excitement to come from this captivating subject in future.

References

1. Michell, J. On the means of discovering the distance, magnitude, &c. of the fixed stars, in consequence of the diminution of the velocity of their light, in case such a diminution should be

found to take place in any of them, and such data should be procured from observations, as would be farther necessary for that purpose, *Phil. Trans. R. Soc.* (London) 74, 1784, pp. 35–57.
2. Einstein, A. Die feldgleichungen der gravitation, Preuss. Akad. Wiss. Berlin Sitzber, 1915, pp. 844-847.
3. Schwarzschild, K. Über das Gravitationsfeld eines Massenpunktes nach der Einstein'schen Theorie, Preuss, Akad. Wiss. Berlin Sitzber, 1916, pp. 189-196.
4. Chandrasekhar, S. The Maximum Mass of Ideal White Dwarfs, *Astrophys. J.* 74, 1931, pp. 81-82.
5. Oppenheimer, J. R, and H. Snyder. On continued gravitational contraction, *Phys. Rev.* 56, 1939, pp. 455-459.
6. Penrose, R. Gravitational collapse and space-time singularities, *Phys. Rev. Lett.* 14, 1965, 57.
7. Wheeler, J. A., and K. Ford. *Geons, Black Holes, and Quantum Foam: A Life in Physics*, New York: W. W. Norton & Co., 1998.
8. Shields, G. A. A brief history of active galactic nuclei, *Pub. Astron. Soc. Pacif.* 111, 1999, pp. 661-678.
9. Schmidt, M. 3C 273: A star-like object with large red-shift, *Nature* 197, 1963, 1040.
10. Bowyer, S., Byram, E. T., Chubb, T. A., et al. Cosmic X-ray sources, *Science* 147, 1965, pp. 394-398.
11. Webster, B. L., and P. Murdin. Cygnus X-1 – a spectroscopic binary with a heavy companion? *Nature* 235, 1972, pp. 37-38.
12. Gillessen, S., Eisenhauer, F., Trippe, S., et al. Monitoring stellar orbits around the massive black hole in the galactic center, *Astrophys. J.* 692, 2009, pp. 1075-1109.
13. Abbott, B. P., Abbott, R., Abbott, T. D., et al. Observation of gravitational waves from a binary black hole merger, *Phys. Rev. Lett* 116, 2016, 061102.
14. Broderick, A. E., Narayan, R., Kormendy, J., et al. The event horizon of M87, *Astrophys. J.* 805, 2015, 179.
15. Ghosh, P. First ever black hole image released, https://www.bbc.co.uk/news/science-environment-47873592, accessed 23rd September 2020.
16. https://www.bbc.co.uk/news/science-environment-54268957?intlink_from_url=&, accessed 23td September 2020.
17. Abbott, R., Abbott, T. D., Abraham, S. Properties and Astrophysical Implications of the $150M_e$ Binary Black Hole Merger GW190521, *Astrophys. J. Lett.* 900, 2020, L13.

Further reading

Castelvecchi, D. 'It's mindboggling!': astronomers detect most powerful black hole collision yet, *Nature* 585, 2020, pp. 171-172.
Celotti, A., et al. Astrophysical evidence for the existence of black holes, *Classical and Quantum Gravity* 16 (12A), 2008.
Naryan, R., and J. E. McClintock. Observational evidence for black holes.https://www.cfa.harvard.edu/~narayan/Benefunder/Narayan_McClintock.pdf, 2014, accessed 23rd September 2020.
Gravitational wave detection – information about the science behind detection and detections made by LIGO to date https://ligo.org/detections.php, accessed 26th September 2020.
Roger Penrose wins 2020 Nobel Prize in Physics for discovery about black holes, https://www.cam.ac.uk/research/news/roger-penrose-wins-2020-nobel-prize-in-physics-for-discovery-about-black-holes, accessed 4th November 2020,