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Theories on Supermassive Black Holes

A black hole is believed to be the result when a star with three or more solar masses exhausts its nuclear fuel and collapses under its own intense gravity to form a space-time singularity. The singularity of a black hole is enveloped by a surface called the horizon that allows particles and light to enter but not to leave. The two types of black holes are Kerr black holes, or rotating black holes, and Schwarzschild black holes, or nonrotating black holes. Initially, black holes were only a theoretical consequence of Einstein's general theory of relativity. "Astronomers have now identified at least 15 black holes in just the Milky Way Galaxy" (Peters). Perhaps the most interesting types of black holes, however, are the the supermassive black holes, which are millions to billions of times more massive than the Sun. "Dormant supermassive black holes reside at the centers of nearly all present-day galaxies, and their presence has been detected through the orbital motions of stars and gas near the galactic centers" (Barger). This paper will specifically go in depth on the theories and arguments surrounding supermassive black holes.

Shortly after Albert Einstein formulated the general theory of relativity in 1916, the solution of the field equations corresponding to a nonrotating black hole was found. For many years, this solution, called the Schwarzschild solution, was used to describe the gravitational attraction outside a spherical star. However, the interpretation of the Schwarzschild solution as a solution for a black hole was not made at the time. More than 20 years elapsed before it was shown that such a black hole could, and probably would, be formed through the gravitational collapse of a nonrotating star of sufficient mass. It was not until 1963 that the solution for a spinning black hole, the Kerr solution, was found. This was particularly important, since most stars are rotating, and the rotation rate is expected to increase when such stars collapse.

"Although some collapsing rotating stars might avoid becoming black holes by ejecting matter, thereby reducing their mass, many stars will evolve to a stage of catastrophic collapse in which the formation of a black hole is the only conceivable outcome. However, unlike in the case of nonrotating black holes, no one has shown that a collapsing rotating star of sufficient mass must form a Kerr black hole" (Peters). On the other hand, it has been shown that if the collapse of a star proceeds past a certain point, the star must evolve to a "singularity," that is, an infinitely dense state of matter beyond which no further evolution is possible. Such singularities are found inside black holes in all known black hole solutions. "It has only been conjectured that the singularity produced in a collapse must be inside a black hole; however, the existence of a naked singularity would have undesirable consequences, such as allowing the violation of fundamental laws of physics that appeal to the conservation of mass-energy and to causality" (Peters). The cosmic censorship theorem is based on the conjecture that the formation of a naked singularity is impossible.

Black hole solutions have also been found for the case in which the black holes have a charge, that is, an electrical as well as a gravitational influence. However, since matter on a large scale is electrically neutral, black holes with any significant charge are not expected in astronomy. Similarly, black hole solutions allow black holes to possess magnetic charge, that is, a magnetic single-pole interaction. "Although some elementary-particle theories predict that particles with magnetic charge, called magnetic monopoles, should exist, sufficient experimental evidence to confirm their existence is not yet available" (Peters). Even if monopoles did exist, they would play little part in the formation of black holes, and so astronomical black holes are expected to be both electrically and magnetically neutral.

Uniqueness theorems about black holes make it likely that at least some Kerr black holes would be formed. Uniqueness theorems address the question of how many kinds of black holes could exist and how complicated their structure could be. These theorems show that black holes must have a simple structure. In fact, the mass, spin, charge, and magnetic charge are all that are needed to specify a black hole completely. Furthermore, any distortion of a black hole, such as that caused by a chunk of matter falling inside, is removed by a burst of radiation. Therefore, although the collapse of a rotating star would be quite complicated, it appears that the final system, the Kerr black hole, would be relatively simple and independent of the details of collapse.

The possible formation of black holes depends critically on what other end points of stellar evolution are possible. Chunks of cold matter can be stable, but their mass must be considerably less than that of the Sun. For masses on the order of a solar mass, only two stable configurations are known for cold, evolved matter. "The first, the white dwarf, is supported against gravitational collapse by the same quantum forces that keep atoms from collapsing. However, these forces cannot support a star whose mass exceeds about 1.2 solar masses. A limiting value of 1.4 solar masses was first found by S. Chandrasekhar and is known as the Chandrasekhar limit. More realistic models of white dwarfs, taking nuclear reactions into account, lower this number somewhat, but the actual value depends on the composition of the white dwarf" (Peters). The second stable configuration, the neutron star, is supported against gravitational collapse by the same forces that keep the nucleus of an atom from collapsing. There is also a maximum mass for a neutron star, estimated to be between 1 and 3 solar masses, with the uncertainty being due to the poor knowledge of nuclear forces at high densities. Both white

dwarfs and neutron stars have been observed, the former for many years at optical wavelengths and the latter more recently in the studies of radio pulsars and binary x-ray sources.

It would appear from the theory that if a collapsing star of more than 3 solar masses does not eject matter, it has no choice but to become a black hole. There are, of course, many stars with mass larger than 3 solar masses, and it is expected that a significant number of them will reach the collapse stage without having ejected sufficient matter to take them below the 3-solar-mass limit. Furthermore, more massive stars evolve more rapidly, enhancing the rate of formation of black holes. It seems reasonable to conclude that a considerable number of black holes should exist in the universe. One major problem is that, since the black hole is dark, it is itself essentially unobservable. Fortunately, some black holes may be observable in the sense that the black hole maintains its gravitational influence on other matter, and thus it can make its presence known. This is precisely how, in a binary system in which a black hole has a massive stellar companion, some of the ejecta from the evolving massive star are accreted by the black hole and yield a distinct x-ray signature. "Otherwise, the detection of a black hole would be limited to observations of the collapse of a star to a black hole, a rare occurrence in the Milky Way Galaxy and one that happens very quickly. Astronomers expect that such collapses would occur about once every thousand years in our galaxy" (Peters). By continuously surveying many thousands of galaxies, one could therefore hope to detect black hole formation. This is the goal of detectors that are under construction to search for gravitational waves from stars that are collapsing and binary neutron stars that are merging to form black holes.

Works Cited

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