Black holes

1. Introduction

What is a black hole? Roughly it can be described as a region of spacetime where gravitational collapse of matter resulted in the gravitational attraction becoming so strong that nothing can escape from it. Light falling into a black hole cannot escape from it. It is called 'black' because it does not reflect anything. Since nothing can escape from it, it means that a black hole's escape velocity is infinite. The escape velocity of a celestial body can be calculated using the formula

$V_e = \sqrt{2GM}/R$

G is the gravitational constant, M is the mass of the celestial body and R is the radius. Using this formula to calculate the escape velocity of the Earth, it is found to be 11.2 km/s. On the other hand the escape velocity of a black hole is infinite. (1)

Roger Penrose (2) showed that this (the formula above) happens in Newtonian theory where the speed of light has no absolute status. Since we deal with a situation where the escape velocity of the black hole exceeds the speed of light we require a general-relativistic spacetime rather than a Minkovski space. In general relativity situations will occur in which the escape velocity exceeds the speed of light.

Black holes were first conceived of by the British mathematician John Mitchell in 1783, (see 1). However, it was only when Einstein formulated his general theory of relativity that a proper understanding of a black hole as the curvature of spacetime could be arrived at. Schwarzschild was the first to use Einstein's equation to describe a spherical non-rotating body. The term black hole was first introduced by the American physicist John Wheeler. Black holes were further extended by the discovery of solutions to Einstein's equation describing charged black holes, known as the Reissner-Nordstrom black holes- and rotating black holes named after Roy Kerr. (See1) Prof. Stephen Hawking played a leading role in the mathematical description of black holes in the 1970's and 1980's.

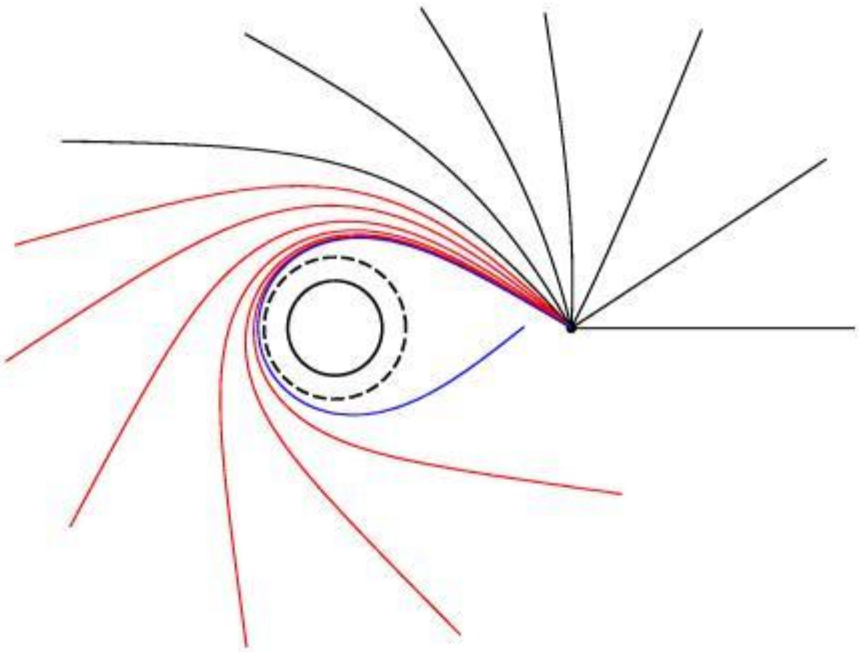
2. Black holes

A black hole can occur where the inward pressure of a very massive body, say 10 solar masses (ten times the mass of the Sun), can no longer prevent the inward collapse of the outer layers of the body. When no more energy can be produced at the core of the star, the collapse of the body becomes unstoppable and a black hole forms. The escape velocity of the body exceeds the speed of light; we can also say it becomes infinite.

The picture becomes more complicated when the electrons or neutrons become *degenerate.* This has to do with the Pauli Exclusion Principle which states that no two or more fermions can occupy the same quantum state. This result in a *white dwarf* where the electrons are held apart by electron degeneracy pressure or a *neutron star* where neutrons are held apart by neutron degeneracy pressure. In terms of general relativity the degeneracy pressure cannot hold a star apart if the mass exceeds 2 solar masses. This result was obtained by Chandrasekhar in 1931 when he calculated such a limit as 1.4 solar masses. The collapse of the object becomes unstoppable and it forms a *black hole*.

At the centre of the black hole is a singularity of infinite gravitational pull and infinite density which is surrounded by an invisible *event horizon*, which is merely a point at which it becomes impossible for any infalling object to escape from the gravitational pull of the black hole.

The strong gravitational pull of the black hole has surprising effects. Close to the event horizon infalling objects experience a strange kind of gravitational pull; a **tidal force**. A person orbiting a black hole will feel a stronger pull of the part of his body closest to the black hole. This is because gravity obeys the inverse square law. If you are one kilometre away from the black hole gravity will be twice as strong as two kilometres away. Once an object crosses the invisible event horizon tidal forces will shred it to pieces in a process known as spagetification. Because we cannot see beyond the event horizon exactly what happens to matter once it crosses this point cannot be determined observationally.



The bending of light by the gravitational pull of a black hole.

3. Quantum black holes

According to general relativity nothing can ever escape from a black hole. In 1975 Prof. Stephen Hawking proved mathematically that, according to the quantum theory, black holes will radiate energy and evaporate. He showed that when virtual particles formed at the event horizon, it is possible that the particles will not annihilate but one might fall into the black hole and the other escapes to infinity. The black hole will therefore loose energy/mass. This process has become known as the **Hawking Radiation**.

(1) Liddle A and Loveday J. 2008. Oxford Companion to Cosmology, Oxford University Press.

(2) Penrose R. 2005. The Road to Reality. A Complete Guide to the Laws of the Universe. Vintage Books, London UK.