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Black Holes and Gravitational Waves

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Introduction

Black holes are created when a star whose mass is greater than a certain limit (called a Chanrasekhar Limit) collapses and forms a void with a gravitational force so strong not even light can escape. Black holes emit Hawking Radiation, after Stephan Hawking. The Hawking Radiation is given as

kT = hbarg/(2pi c) = hbarc/(4pi rs)

Where k = Boltzmann's constant 1.38x10-23J/K,

Hbarc = Plank's constant divided by 2 pi 1.054x10-23Js,

g = surface gravity at horizon GM/rs^2 with rs = Schwarzchild radius of black hole with mass M and G = 6.6742x10^11Nm^2/kg^2 (gravitational constant).

The Scharzchild Radius predicts the black hole's event horizon, which is the point on the horizon where nothing can escape its gravitational force (1).

Gravitational Waves

Einstein's General Theory of Relativity first predicted the existence of gravitational waves in 1915. They were thought to exist because gravity warps the space-time continuum. A collision of this warping with another warping of sufficient strength would produce a ripple effect. This effect is similar to throwing two rocks into a pond and watching the water ripples collide with each other.

In 1961, Joseph Weber of the University of Maryland developed a gravitational wave detector device consisting of an aluminum bar two meters (6.5 feet) long oriented broadside to the waves. The waves were predicted to first compress, and then stretch, the bar's ends, thus causing it to resonate like a tuning fork. The resonant frequency was predicted to be below about 10,000 Hertz (cycles/second) (2).

If the bar resonated at this frequency without being effected by outside forces, Weber could infer the existence of gravitational waves. The sensor used to measure this tiny perturbation was made from a piezoelectric crystal.

In 1999, work was completed on the Laser Interferometer Gravitational-Wave Observatory (LIGO). The project was a joint effort between scientists at the California Institute of Technology and Massachusetts Institute of Technology.

The detectors were installed in two locations, one in Livingston, Louisiana, and one in Hanford, Washington. As shown in Fig. 1, each detector consists of a 1.2-meter (4-feet) diameter vacuum tube in the shape of an L with 4-kilometer (2.5 mile) arms. The entire site is covered with concrete. Test masses with mirrors are hung from the corner and at each end of the L. Laser beams aimed the length of the vacuum tube measure the effect of the gravitational waves on the test masses (3).

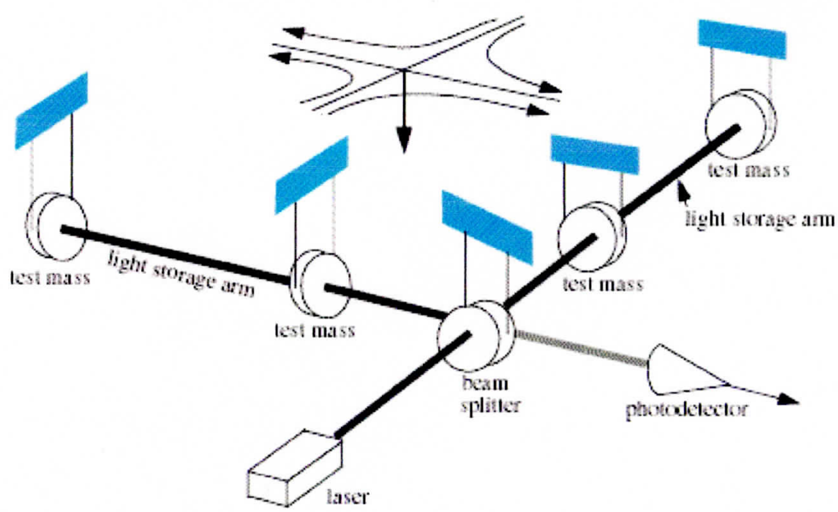

Figure 1. Diagram of the LIGO (courtesy of

www.ligo.caltech.edu/LIGO_web/about/factsheet.html).

The detectors are looking for movements on a very small scale, 10-16 centimeters, or one-hundred-millionth the diameter of a hydrogen atom. This change is to be measured over the four-km length of the tube.

At least two detectors are required to rule out interference from local disturbances, such as seismic activity. An identical signal at both detectors indicates a gravity wave, while a signal at only one detector can be ignored. Ideally, LIGO observations will be compared with results from gravitational wave detectors now under construction in several other countries.

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The causes of gravitational waves are thought to be events that cause ripples in the fabric of space-time. A typical event would be either an explosion of a massive star (supernova) or the collision of two black holes. One black hole is not sufficient to produce gravitational waves, because the event horizon would concentrate its own gravity.

However, if two black holes were to collide, ripples in the space-time fabric could propagate outwards, much like the previous mentioned ripples on the surface of a pond. This is illustrated in Fig. 2.

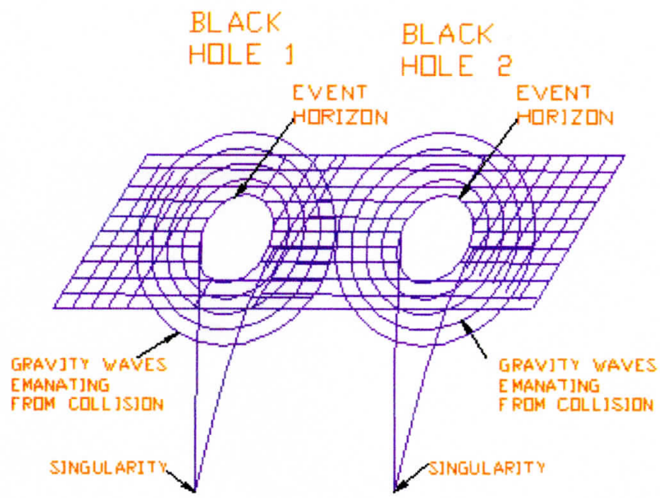

Figure 2. Diagram illustrating hypothetical propagation of ripples in the space-time fabric caused by the collision of two black holes. Diagram by Scott Little.

The force of these waves may be increased by more collisions with subsequent waves, as when ocean waves bounce off a dock and collide with incoming waves. This is known as the Wedge Effect.

The curvature of space-time is the underlying reason that gravitational waves are possible. The field equation that defines General Relativity and the curvature due to gravity is:

Rik- gikR/2+L gik= 8pG/c^4Tik

Where Rik = the Ricci curvature tensor, R = the scalar curvature, gik = the metric tensor, L = 8pG/3c^2r (Einstein's cosmological constant), Tik = the stress-energy tensor non-gravitational matter, energy, and forces at any given point in space-time, c = the speed of light in a vacuum, G = the gravitational constant from Newton's Law of Gravitation, and p = 3.1416.

The basic tenant of the Einstein field equation is that the curvature of space-time is directly affected by the force of gravity applied by the mass of the object. It also takes into account the measurement of the curvature (gik), the non-gravitational forces (Tik), and the interrelations of fields. In an oversimplified way it states, "curvature tells matter how to move, and matter tells space how to curve (4).

Have gravitational waves been detected?

While LIGO scientists have established noise limits for their system, so far they have not unequivocally detected gravitational waves. Because detectable gravitational wave events are believed to be rare, years of simultaneous observations by the LIGO detectors may be required before a gravitational wave event is detected. Meanwhile, LIGO scientists have proposed an improved detector with ten times the sensitivity of the current LIGO.

For more information about the current status of LIGO, see the LIGO web site *www.ligo.caltech.edu/LIGO_web/about/factsheet.html*. For more information about gravitational waves, consider searching on relevant key words using a search engine such as www.google.com.

References

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