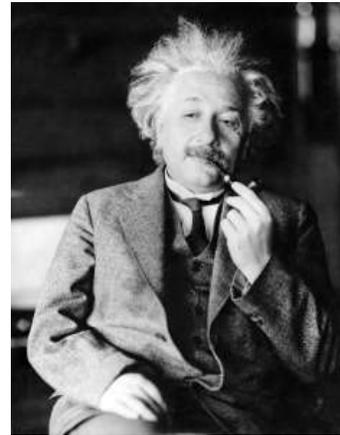


Einstein and the Special and General Theories of Relativity

Special Theory of Relativity

Albert Einstein (1879 – 1955) used the geometric concepts of Lobachevsky and Riemann in his Special Theory of Relativity (1905) that states that the speed of light is the same for all inertial observers regardless of the state of motion of the source emitting the light.



The speed of light (already discovered by Maxwell) is the fastest speed at which energy or information can travel, and is only attained by **massless particles** and **waves** such as electromagnetic radiation (e.g. radio waves, visible light, or gamma rays) in a vacuum, where there are no atoms, molecules or other types of matter that can slow it down. Its value is exactly 299,792,458 metres per second, often approximated as 300,000 kilometres per second. This is **1,079 million** km/h.

In **Special Relativity** Einstein posited that the **speed of light is constant** (c) and that the speed at which light propagates in vacuum is independent both of the motion of the light source and of the inertial frame of reference of the observer. c connects space and time in the unified structure of **spacetime**, and its square is the constant of proportionality between mass and energy ($E = mc^2$). His Special Relativity led to counter-intuitive conclusions such as **length contraction**, **time dilation**, and **relativity of simultaneity**.

See following flash animations by David Harrison of the U.of T.'s Physics Dept.:

<http://tinyurl.com/tok-length-contraction>
<http://tinyurl.com/tok-simultaneity>

- Actual (minutely) measurable time dilation effects were confirmed in successive tests in the 1970s when atomic clocks were flown at speed on jets and compared to an identical clock fixed on the earth's surface. GPS has subsequently confirmed time dilation and, indeed, needs to account for the relativistic effect of time in order to be accurate.

General Theory of Relativity

In 1915 Einstein published his **General Theory of Relativity** (updated in 1919). It describes gravity (G) not as an attractive force between bodies as Newton had explained—where objects with mass attract other objects to them—but instead as a geometric property of space and time, or spacetime. Space and time are inextricably linked in a fabric, and objects with mass warp/bend spacetime and this distortion in spacetime has an effect on everything passing through it.

The Geodetic Effect

Consider a bowling ball in the centre of a trampoline: the trampoline is spacetime, the bowling ball an object with mass. The fabric of spacetime is flat until where it is

distorted by the bowling ball's weight and the trampoline sags. Now consider rolling a tennis ball by the bowling ball. As it approaches the bent / distorted fabric of spacetime that is the trampoline, it will roll towards the bowling ball. Thus the tennis ball is not attracted to the bowling ball by the force of gravity exerted by the bowling ball itself, but the effect that it has on the fabric of space time. If the velocity of the tennis ball is just right, it will continue to circle the bowling ball in an orbit rather than falling into it; if its velocity is great enough, the tennis ball will be affected by the distortion in spacetime, but will escape a continuous orbit around the bowling ball.

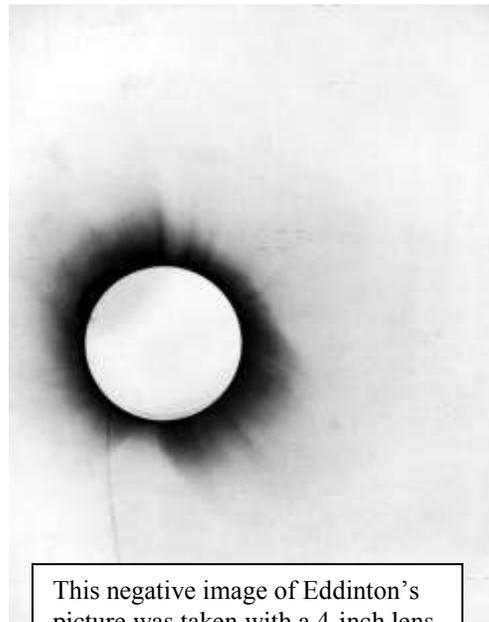


Geodetic effect: The moon orbits the earth by following the distortion in the fabric of spacetime that the earth creates.

According to the General Theory of Relativity, matter and energy affect the fabric of spacetime, and the greater the mass of an object the greater the effect. Thus stars and planets distort the fabric of spacetime, known as the '**geodetic effect**'.

** Everything that passes through the fabric of spacetime is affected by these distortions, including massless properties like light. **
e.g. Light can be bent by gravity.

The **geodetic effect** on light was proven during a solar eclipse in 1919, *several years after Einstein's Theory of General Relativity was published*. Sir Arthur Eddington photographed a total eclipse of the sun in which light from stars that were known to be actually behind the sun still reached earth!! This was possible because their light was bent around the sun by travelling through the distorted fabric of spacetime caused by the sun.



This negative image of Eddington's picture was taken with a 4-inch lens at Sobral, Brazil. The horizontal lines are starlight bent by the sun.

- **Take Home Point:** Einstein's Theories of Special and General Relativity have had a wide range of consequences which have been experimentally verified, AFTER Einstein's math proofs.
- The math came first, then experiments/observation confirmed it later.

Frame Dragging

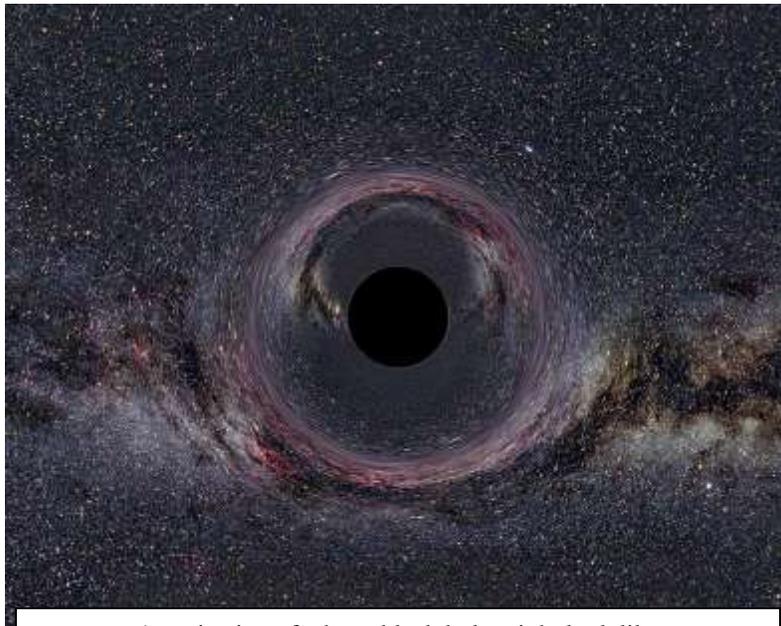
We are still in the process of proving aspects of Einstein's Theory of General Relativity. Apart from the geodesic effect, he also predicted **frame dragging**, where rotating bodies (like planets) not only bend the fabric of spacetime, but also pull/drag it with them in their direction of rotation.

The effect is very slight, and only recently has the technology been available to measure it accurately. NASA and Stanford University's [Gravity B Probe](#) has, as recently as 2010, confirmed Einstein's predictions.

Ninety years later, his equations are being proven right. Experimentation and observation postdate the math. **The math came first.**

Black Holes

Einstein's General Theory of Relativity predicted the effects of a Black Hole – an event where a star collapses upon itself as it dies. Black Holes are so incredibly dense that they create massive disruptions in the fabric of spacetime – so much so that that not even light can escape from them.



A projection of what a black hole might look like (though they do not look like anything: they are invisible!).

The Hubble Space Telescope has measured what astronomers believe to be black holes. Since light does not emanate from them they cannot actually be seen, but the behaviour of stars around them suggests a massive gravitational force/spacetime disruption.

Again, scientific observation seems to confirm Einstein's theories. **The math came first.**