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THEORY OF GENERAL RELATIVITY: HISTORICAL PERSPECTIVE

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Abstract

General relativity was developed by Albert Einstein near about 100 Years ago. This article attempt to give an outline about the brief history of general theory of relativity and to understand the background to the theory we have to look at how theories of gravitation developed. Before the advent of GR, Newton's law of gravitation had been accepted for more than two hundred years as a valid description of the gravitational force between masses i.e. gravity was the result of an attractive force between massive objects. General relativity has developed in to an essential tool in modern astrophysics. It provides the foundation for the understanding of black holes, regions of space where gravitational attraction is strong that not even light can escape and also a part of the big bang model of cosmology. .

Key words

Gravitation; cosmology; big bang; black holes; gravitational lensing

Introduction

General relativity or the general theory of relativity (GR) is the geometric theory of gravitation published by Albert Einstein in 1916 and the current description of gravitation in modern physics. General relativity generalizes special relativity and Newton's law of universal gravitation, providing a unified description of gravity as a geometric property of space and time or space time. In particular, the curvature of space time is directly related to the energy and momentum of whatever matter and radiation are present. The relation is specified by the Einstein field equations, a system of partial differential equations.

Some predictions of general relativity differ significantly from those of classical physics, especially concerning the passage of time, the geometry of space, the motion of objects in free fall, and the propagation of light. Examples of such differences include gravitational wave, gravitational time dilation, gravitational lensing, the gravitational redshift of light and the gravitational time delay. Although general relativity is not the only relativistic theory of gravity, it is the simplest theory that is consistent with experimental data.

Many of these predictions have been confirmed by experiment, while other is the subject of on-going research. For example, indirect evidence for gravitational waves, direct evidence of their existence is still being sought by several teams of scientists in experiments such as LIGO and GEO 600 projects (Lehnere et al., 2012).

Before the development of general relativity, Newton's law of universal gravitation had been accepted for more than 200 years as a description of the gravitational force between masses, within a century of Newton's formulation, astronomical observation revealed unexplainable variations between the theory and observations. General relativity has developed into an essential tool in modern astrophysics. It provides the foundation for the current understanding of black holes, regions of space where gravitational attraction is so strong that not even light can escape. Their strong gravity is thought to be responsible for the intense radiation emitted by certain types of astronomical objects such as active galactic nuclei or micro quasars. General relativity is also a part of the framework of the standing big bang model of cosmology (Cloey, 1995).

History of general relativity

After publishing the special theory of relativity in 1905, Einstein started to think about how to incorporate gravity into his new relativistic framework. In 1907, he wrote an article on acceleration under special relativity and argued that free fall is really inertial motion and that for a freefalling observer the rules of special relativity must apply. This argument is called equivalence principle. In the same article Einstein also predicted the phenomenon of gravitational time dilation and realized that the principle of relativity could be extended to gravitational fields.

In 1911, Einstein published another article expanding on the 1907 article about the case of a uniformly accelerated box not in a gravitational field and noted that it would be indistinguishable from a box sitting still in an unchanging gravitational field. He used special relativity to see that the rate of clocks at the top of box accelerating upward would be faster than the rate of clocks at the bottom. He conclude that the rates of clocks depend on their position in a gravitational field and the difference in the rate in proportional to the gravitational potential to first approximation. At the same time, he also discussed about the gravitational redshift, light leaving a massive body will be shifted towards the red by the energy loss of escaping the gravitational field (Pais, 1982).

Further In 1912, Einstein published a paper on gravitation and realized that the Lorentz transformation will not apply and also realized that the gravitational field equation were bound to be non linear and equivalence principle hold locally. On the basis of this work, Nordstrom, Abraham and Mie were failed to find the satisfactory theory of gravitation. After this, Einstein realized his problem, if all accelerated systems are equivalent, then Euclidean geometry cannot hold in all of them. He consulted his friend Marcel Grossmann who was able to introduce the important development of Riemannian geometry and differential geometry (Einstein & Grossmann, 1913).

On the recommendation of Italian mathematician Tullio Levi-civita and Ricci Curbastro, Einstein began exploring the usefulness of general covariance i.e. uses of tensors for his gravitational theory. In 1914, Einstein wrote a paper and explained a treatise on tensor analysis and differential geometry. This paper led to a correspondence between Einstein and Levi-civita in which Levi-civita pointed out technical errors in Einstein's work on tensors.

In this way Einstein thought that there were problems with the approach and in 1915 he published a paper which is known as Einstein's field equations. These equations specify how the geometry of space and time is influenced by matter and radiations. These field equations are nonlinear and were very difficult to solve. But in 1916, astrophysicist Karl Schwarzschild found the mathematical solution to the Einstein field equations which correspond to the gravitational field of a massive compact object. At that time this was purely theoretical work. Einstein reached the final version of general relativity after slow progress. In March 1916, Einstein completed a paper explaining general relativity in terms easily understandable terms. The paper was well recognized and he then wrote another paper on relativity which was widely read. Today relativity plays role in many areas: cosmology, the big bang theory, etc. and has been checked by experiment to a high degree of accuracy (John, 2002).

Einstein's space and the development of the Einstein's field equation

Einstein's in the years 1911 to 1916 depend on the development in the field of differential geometry. And it is also true that the general relativity is strongly induced the subsequent development of geometry. So it can remark on the relation between mathematics and physics in general and general relativity and Riemannian geometry in particular i.e. the concept of an Einstein's space. The characteristic feature of mathematics has been explained as "Mathematics is that study that knows nothing observations, nothing of experiment, nothing of induction, nothing of causation." It can be compared to Einstein's remarks "It is possible that the mathematics, which after all is product of human thought independent of all experiences, is so admirably adapted to real objects (Prasad, 2006).

When Einstein realized the general concept of differential geometry and tensor analysis, he completed the development of the field equations, and published in October 1915 and is known as Einstein's field equation. This equation satisfy the geometry of space and time influenced by matter and radiation,

i.e. $R_{\mu\nu} = T_{\mu\nu}$

Where $R_{\mu\nu}$ is the Ricci tensor and $T_{\mu\nu}$ is the energy momentum tensor. This predicted the non Newtonian perihelion precession of Mercury. However, it was soon realized that they were inconsistent with the local conservation of energy momentum unless the universe had a constant density of mass energy momentum. In other word, air, rock and even a vacuum should all have the same density. However, the solution was obvious and on November 29, 1915 Einstein presented the actual Einstein field equation to the Purssian Academy of Sciences.

$R_{\mu\nu} -1/2\, Rg_{\mu\nu} = T_{\mu\nu}$

Where $R_{\mu\nu}$ is the Ricci scalar and $g_{\mu\nu}$ is the metric tensor (Robertson et al, 1968)

The expanding universe of cosmological constant

The current models of cosmology are based on the Einstein's field equation. In 1922, Alexander Friedmann found in which the universe may expand or contract and later Georges Lemaitre derived a solution for an expanding universe. However, Einstein believed that the universe was apparently static and since a static cosmology was not supported by the general relativistic field equation. Einstein include the cosmological constant Λ to the field equations, which became

$R_{\mu\nu} -1/2\, Rg_{\mu\nu} + \Lambda g_{\mu\nu} = T_{\mu\nu}$

This permitted the creation of steady state solutions, but they were unstable. The slightest perturbation of a static state would result in the universe expanding or contracting (Lemaitre, 1933).

In 1929 Edwin Hubble found evidence for the idea that the universe is expanding. This resulted in Einstein dropping the cosmological constant referring to it as "the biggest blunder" At the time it was an ad-hoc hypothesis to add in cosmological constant as it was only justify the result (a static universe).

Alternative theories

There have been various attempts to find the modification of general relativity. The most famous theory is Brans Dicke theory known as scalar tensor theory and Rosen's biometric theory. Both of these theories proposed changes to the field equations of general relativity and both suffer from these changes permitting the presence of bipolar gravitational radiation. In addition, general relativity is inconsistent with quantum mechanics, the physical theory that describes the wave particle duality of matter and quantum mechanics does not describe gravitational attraction at microscopic scales. The speculative theory that unites general relativity and quantum mechanics is usually called quantum gravity, prominent examples of which the string theory and loop quantum gravity (Thorn, 2003).

Application of general relativity

Einstein's theory has important astrophysical implications, for example: - it implies the existence of black holes- regions of space in which space and time are distorted in such a way that nothing, not even light, can escape as an end state for massive stars. There is an evidence that the intense radiation emitted by certain kinds of astronomical objects in due to black-holes. The bending of light by gravity can lead to the phenomenon of gravitational leasing in which multiple images of same distant astronomical object are visible in the sky. General relativity also predicts the existence of gravitational waves, which have been observed indirectly, a direct measurement is the aim of projects, such as LIGO and NASA/ESA Laser interferometer space, Antenna and various timing arrays.

Conclusion

General relativity has highly successful model of gravitation and cosmology which so far passed many unambiguous observational and experimental tests. However there are strong indications the theory is incomplete. The phenomenon of quantum gravity and equation of the reality of space time singularities remain open. Observational data that is known as evidence for dark energy and dark matter could indicate the need for new physics. Near about hundred years after its publication, general relativity remains a highly active area of research. Today relativity plays a roll in many areas such as cosmology, the big-bang theory, black-holes, gravitational wave etc. and how has been checked by experiment to a high degree of accuracy.

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