Exploring Alternatives to General Relativity in the Modern Era: From Hendrik Lorentz to Quantum Gravity Models

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Commentary

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ABOUT THE STUDY

In 1900, Hendrik Lorentz tried to explain gravity on the basis of his ether theory and Maxwell's equations. He assumed, like Ottaviano Fabrizio Mossotti and Johann Karl Friedrich Zöllner, that the attraction of opposite charged particles is stronger than the repulsion of equal charged particles. The resulting net force is exactly what is known as universal gravitation, in which the speed of gravity is that of light. Lorentz calculated that the value for the perihelion advance of Mercury was much too low. In the late 19th century, Lord Kelvin pondered the possibility of a theory of everything. He proposed that everybody pulsates, which might be an explanation of gravitation and electric charges. His ideas were largely mechanistic and required the existence of the aether, which the Michelson–Morley experiment failed to detect in 1887. This, combined with Mach's principle, led to gravitational models which feature action at a distance.

Albert Einstein developed his revolutionary theory of relativity in papers published in 1905 and 1915; these account for the perihelion precession of Mercury. In 1914, Gunnar Nordström attempted to unify gravity and electromagnetism in his theory of five-dimensional gravitation. General relativity was proved in 1919, when Arthur Eddington observed gravitational lensing around a solar eclipse, matching Einstein's equations. This resulted in Einstein's theory superseding Newtonian physics. Thereafter, German mathematician Theodor Kaluza promoted the idea of general relativity with a fifth dimension, which in 1921 Swedish physicist Oskar Klein gave a physical interpretation of in a prototypical string theory, a possible model of quantum gravity and potential theory of everything. Einstein's field equations include a cosmological constant to account for the alleged staticity of the universe. However, Edwin Hubble observed in 1929 that the universe appears to be expanding. By the 1930s, Paul Dirac developed the hypothesis that gravitation should slowly and steadily decrease over the course of the history of the universe. Alan Guth and Alexei Starobinsky proposed in 1980 that cosmic inflation in the very early universe could have been driven by a negative pressure field, a concept later coined 'dark energy'—found in 2013 to have composed around 68.3% of the early universe. In 1922, Jacobus Kapteyn proposed the existence of dark matter, an unseen force that moves stars in galaxies at higher velocities than gravity alone accounts for. It was found in 2013 to have comprised 26.8% of the early universe. Along with dark energy, dark matter is an outlier in Einstein's relativity, and an explanation for its apparent effects is a requirement for a successful theory of everything.

In 1957, Hermann Bondi proposed that negative gravitational mass combined with negative inertial mass would comply with the strong equivalence principle of general relativity and Newton's laws of motion. Bondi's proof yielded singularity-free solutions for the relativity equations.

Early theories of gravity attempted to explain planetary orbits and more complicated orbits. Then came unsuccessful attempts to combine gravity and either wave or corpuscular theories of gravity. The whole landscape of physics was changed with the discovery of Lorentz transformations, and this led to attempts to reconcile it with gravity. At the same time, experimental physicists started testing the foundations of gravity and relativity—Lorentz invariance, the gravitational deflection of light, the Eötvös experiment. These considerations led to and past the development of general relativity.