Commentary on Einstein Field Equations About Gravity and Quantum Mechanics

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Commentary

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ABOUT THE STUDY

The Einstein field equations are a system of 10 partial differential equations which describe how matter affects the curvature of space-time. A major area of research is the discovery of exact solutions to the Einstein field equations. Solving these equations amounts to calculating a precise value for the metric tensor under certain physical conditions. There is no formal definition for what constitutes such solutions, but most scientists agree that they should be expressible using elementary functions or linear differential equations. Some of the most notable solutions of the equations include;

The Schwarzschild solution, which describes space-time surrounding a spherically symmetric non-rotating uncharged massive object. For compact enough objects, this solution generated a black hole with a central singularity. At points far away from the central mass, the accelerations predicted by the Schwarzschild solution are practically identical to those predicted by Newton's theory of gravity. The Reissner–Nordström solution, which analyses a non-rotating spherically symmetric object with charge and was independently discovered by several different researchers between 1916 and 1921. In some cases, this solution can predict the existence of black holes with double event horizons.

The Kerr solution, which generalizes the Schwarzchild solution to rotating massive objects. Because of the difficulty of factoring in the effects of rotation into the Einstein field equations, this solution was not discovered until 1963.

The Kerr–Newman solution for charged, rotating massive objects. This solution was derived in 1964, using the same technique of complex coordinate transformation that was used for the Kerr solution.

The cosmological Friedmann–Lemaître–Robertson–Walker solution, discovered in 1922 by Alexander Friedmann and then confirmed in 1927 by Georges Lemaître. This solution was revolutionary for predicting the expansion of the Universe, which was confirmed seven years later after a series of measurements by Edwin Hubble. It even showed that general relativity was incompatible with a static universe, and Einstein later conceded that he had been wrong to design his field equations to account for a Universe that was not expanding.

Today, there remain many important situations in which the Einstein field equations have not been solved. Chief among these is the two-body problem, which concerns the geometry of space-time around two mutually interacting massive objects (such as the Sun and the Earth, or the two stars in a binary star system). The situation gets even more complicated when considering the interactions of three or more massive bodies, and some scientists suspect that the Einstein field equations will never be solved in this context. However, it is still possible to construct an approximate solution to the field equations in the n-body problem by using the technique of post-Newtonian expansion. In general, the extreme nonlinearity of the Einstein field equations makes it difficult to solve them in all but the most specific cases. Despite its success in predicting the effects of gravity at large scales, general relativity is ultimately incompatible with quantum mechanics. This is because general relativity describes gravity as a smooth, continuous distortion of space-time, while quantum mechanics holds that all forces arise from the exchange of discrete particles known as quanta. This contradiction is especially vexing to physicists because the other three fundamental forces were reconciled with a quantum framework decades ago. As a result, modern researchers have begun to search for a theory that could unite both gravity and quantum mechanics under a more general framework. One path is to describe gravity in the framework of quantum field theory, which has been successful to accurately describe the other fundamental interactions. The electromagnetic force arises from an exchange of virtual photons, where the QFT description of gravity is that there is an exchange of virtual gravitons. This description reproduces general relativity in the classical limit. However, this approach fails at short distances of the order of the Planck length, where a more complete theory of quantum gravity is required.