Einstein and the Gravitational Waves

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In 1918 Einstein published the paper ÜBER GRAVITATIONSWELLEN [1] in which, for the first time, the effect of gravitational waves was calculated, resulting in his famous "quadrupole formula" (QF). Einstein was forced to this publication due to a serious error in his 1916 paper [2], where he had developed the linear approximation ("weak-field") scheme to solve the field equations of general relativity (GR). In analogy to electrodynamics, where accelerated charges emit electromagnetic waves, the linearized theory creates gravitational waves, popagating with the speed of light in the (background) Minkowski space-time. A major difference: Instead of a dipole moment, now a quadrupole moment is needed. Thus sources of gravitational waves are objects like a "rotating dumbbell", e. g. realized by a binary star system.

As there was no chance for detecting gravitational waves, due to their extreme weakness of the order $(\frac{v}{c})^5$, the theory advanced slow in the first decades. The existence of gravitational waves was always a matter of controversy. Curiously Einstein himself was not convinced in 1936. In a paper with Nathan Rosen he came to the conclusion, that gravitational waves do not exist! Curiously too is the story of its publication. Einstein's manuscript, titled DO GRAVITATIONAL WAVES EXIST?, was rejected by the "Physical Review". In an angry reply he withdrawed the paper, to appear later in the "Journal of the Franklin Institute" (choosing a less provoking headline [3]).

To clear the situation, various approximation schemes were developed. One of the first, introduced by Einstein, Infeld and Hoffmann in 1938 [4], led to the famous EIH equations. This "post-Newtonian" treatment describes slow moving bodies in a weak field ("bounded systems"). In the EIH approximation there is no radiation up to the order $(\frac{v}{c})^4$, the energy remains constant. The QF appears in the next order, as demonstrated by Hu in 1947 [5]. What's about fast moving particles? This problem had to wait until the early 1960's, when the Lorentz-invariant perturbation methods ("fast-motion approximation"), describing "unbounded systems", were developed. The question of an analogy to the QF ("radiation damping") was strongly discussed.

In 1975 a major boost was caused by the discovery of the binary pulsar PSR $1913 + 16$ by Hulse and Taylor [6]. Over the next years their data showed a decrease of the period of revolution – as predicted by the QF! But this (indirect) proof – in the "bounded" case – did not stop the controversy: On the contrary, the fight gets even stronger. The different approximation formalisms where criticized by Ehlers, Havas and others [7]. The basic difficulties are: (1) In contrast to electrodynamics, the equations of motion in GR are not a separate part of the theory, but already inherent in the field equations. (2) GR is an essential non-linear theory. Any approximation must treat these facts carefully. After a phase of clarification, introducing new methods (e. g. asymptotic field conditions, post-linear approximations), the believe in gravitational waves, and especially in Einstein's QF, is now stronger than ever – eventually visible in expensive terrestrial and space experiments.

References

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