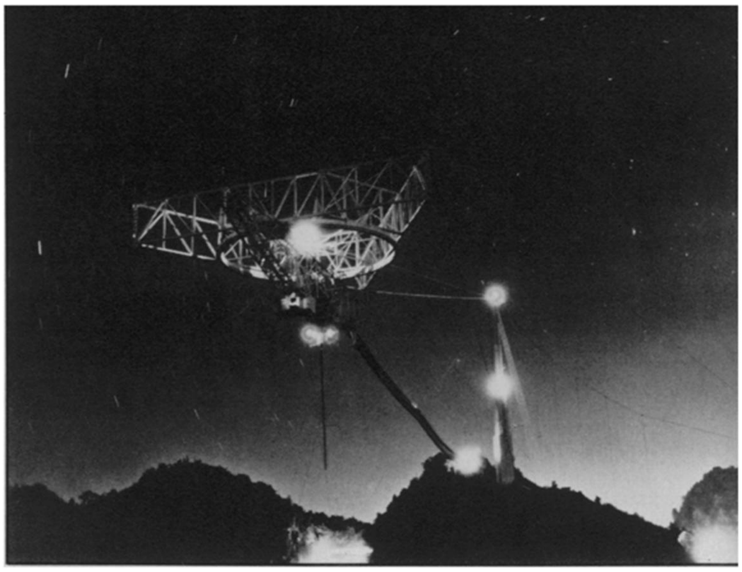
Astrophysical Path to Gravity Waves



Many possible sources of gravity waves are in this picture of the Arecibo antenna.

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Albert Einstein's theory of general relativity is the generally accepted present-day theory of gravity. In that, it is a parallel to James Clerk Maxwell's theory of electromagnetism, which was published about the time that Einstein was born. One of the correspondences between the two theories is that they both predict a phenomenon that seemed absurd to physicists at the times they were published — waves. The waves involve the forces of the theory (electric and magnetic in Maxwell's case, gravitational in Einstein's) and propagate through space and carry energy.

In the case of electromagnetic waves it was not many years before Heinrich Hertz proved their existence with an ironclad experiment that had transmitter and receiver in one room. Now, just a few weeks before Einstein's hundredth birthday, comes the publication of a paper that claims "quantitative confirmation of the existence of gravitational radiation at the level predicted by general relativity." It is by three astronomers from the University of Massachusetts, J.H. Taylor, L.A. Fowler and P.M. McCulloch (on leave from the University of Tasmania).

Oscillating forces that take leave of their source and radiate off through space carrying energy with them seemed outrageous at the time Maxwell published. In physics forces had always pulled toward something or away from something; they didn't undulate around. By the time Einstein published general relativity such ideas were commonplace, but he had wrought a new kind of revolution, the geometrization of physics or the physicalization of space and time. Einstein's waves become, to quote a modern relativist, P.C.W. Davies of Kings College, London, "literally ripples of space-time itself."

One aspect of Einstein's treatment of gravitational forces solved or altered an old problem with Newton's theory, the question of action at a distance. People asked how the earth and the moon could act on each other without touching: Where was the invisible string? Newton had simply to reply that action at a distance is possible. That reply has never been very satisfying.

Einstein made the intervening space the mediator. Gravitational forces are associated with curvature of space. Motions are funneled, so to speak, by the curvature: The moon is following the path of least resistance created by the earth's presence. This attitude makes space and time participants in the physical action. Instead of being an eternal and rigid framework, they become mutable, twistable, stretchable, compressible, reversible. Waves involving gravitational forces and fields are thus undulations of the curvature of space-time, vibrations of the basis of the cosmos.

Taylor, Fowler and McCulloch chose to look for such cosmic vibes in a very cosmic place, the only radio pulsar known to be in a binary system, PSR1913+16. Such close binary systems, systems with very narrow orbits, are expected to radiate gravitational waves at a considerable rate. As they do, they lose energy, and the loss of energy causes the orbit to contract. Over a long enough period of observation this contraction should be evident.

The pulsar has the advantage of sending out precisely timed bursts of electromagnetic radiation (radio), by which its motions in orbit can be followed. The changing Doppler shifts in the frequency of these signals give the geometry of the orbit, telling when the pulsar is approaching the observer, when it is receding, and so forth. They also give an indication of the speed in orbit (a zippy 300 kilometers per second compared to the earth's 18) and of the orbital period. The last is most important for gravitational waves: An elementary law of dynamics that has not been repealed says that if the orbit is shrinking, the period decreases (speed in orbit increases).

In their paper in the Feb. 8 NATURE Taylor, Fowler and McCulloch report on 1,000 observations of the arrival times of PSR1913+16's radio pulses, which span more than four years. They used the world's largest single radiotelescope, the 305-meter dish antenna at Arecibo, Puerto Rico. From these observations they have determined 13 different parameters of PSR1913+16's being and motion. Two of those are the right ascension and declination of its position. Two more are the period of the pulsar's radio pulses and the rate of change of that period with time. The other nine refer to the binary orbit: semimajor axis, eccentricity, binary orbit period ($27{,}906.98172 \pm 0.00005$ seconds or about 7.75 hours), longitude of periastron, time of periastron passage, rate of advance of periastron, transverse Doppler and gravitational redshift, sine of the angle of the orbit to the line of sight and the rate of change of the orbital period with time.

From all this they can box the masses of both the pulsar and its companion into a fairly narrow range around 1.5 times the mass of the sun. From that they can calculate the forces and energies involved, and they conclude that the observed rate of change of orbit period, a decrease of 3.2 trillionths (10^{-12}) of a second per second, indicates that the system is radiating gravitational waves in the amount predicted by Einstein's general relativity and not by other theories of gravity that have been put forward.

Critics have raised the point — Davies mentions it in his comment in the same issue of NATURE — that the formula used is an approximation, and the mathematical complexities of the theory leave some doubt over the accuracy of the calculation. Taylor, Fowler and McCulloch anticipate this and include a technical section to convince other relativists of the sharpness of the formula, but it is sure to be discussed. Davies says, "There is clearly room for more theoretical work here."

A completely Hertzian proof of gravitational waves seems infeasible. To make a gravitational wave generator on earth appears to be impossible. The passive half of the Hertzian experiment, large metal bars intended to be detectors of bursts of gravitational waves coming from space, are in place in a number of laboratories (SN: 3/18/78, p. 169). The effect they are looking for is so delicate that the strongest bursts from space (which PSR1913+16's by no means are) would disturb them as much as a lighted match a million miles away. Knowledgeable people expect it will be years before they find anything, if ever. Meanwhile we shall have to depend on astrophysical proofs like this one, which are proofs by deduction from observation, rather than by actually feeling the rumble. □