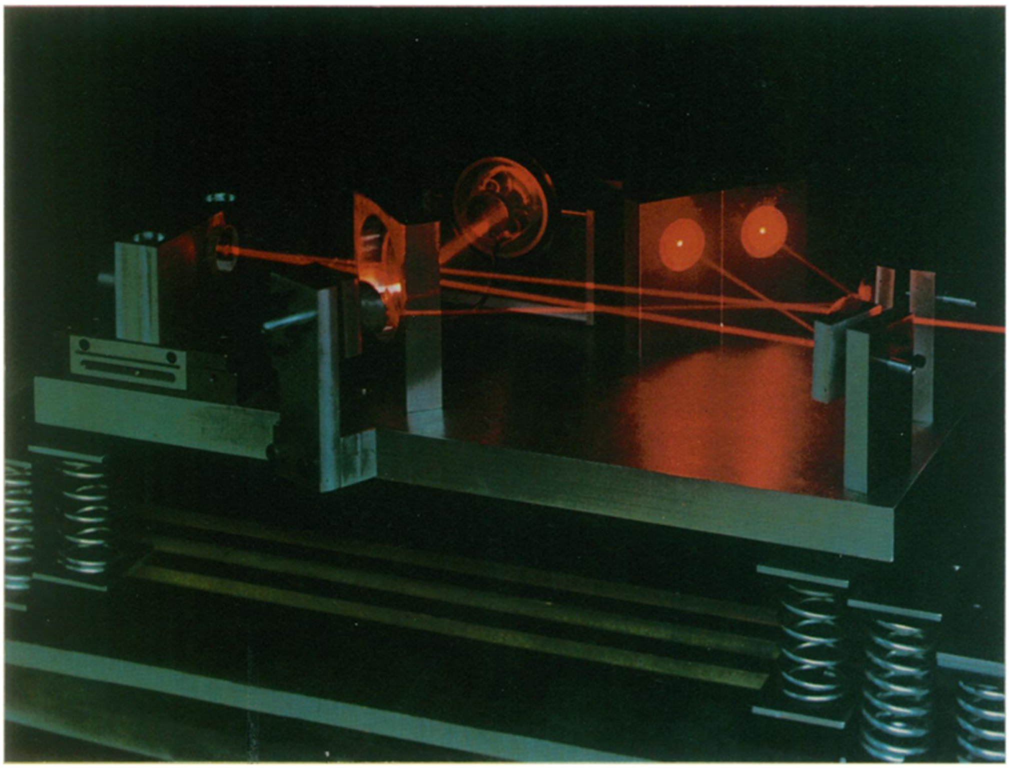
GRAVITY-WAVE ASTRONOMY



Hughes Aircraft Co.

One form of possible gravity-wave detector uses laser beams to detect differential motions of test masses affected by the passage of the waves.

"Gravity waves in astronomy?" Tom said shakenly.
The galaxies give them to you straight from the heart.

BY DIETRICK E. THOMSEN

Astronomy now pretty well covers the spectrum of electromagnetic waves. From the visible portion of the spectrum it has expanded in one direction to decameter radio waves and in the other to high-energy gamma rays. Its next major step is likely to be to an entirely different kind of waves from the electromagnetic variety—gravitational waves.

Kip Thorne of California Institute of Technology believes the move is imminent. At the Symposium on Theoretical Principles in Astrophysics and Relativity held at the University of Chicago at the end of May he issued a plea for general relativists to get busy and calculate the sorts of astrophysical events that might give off significant bursts of gravitational waves to prepare for the day when observations can start.

His view is disputed by Lodewik Woltjer of Columbia University. Woltjer believes that the day of gravitational-wave astronomy is much farther off, and general relativists have no need to saddle up and ride for the pass. The disagreement is more one of timing than of principle. Thorne believes that some of the bodies that will be important in gravitational-wave astronomy are already under observation, and he is eager to extend studies of their astrophysics into realms not now accessible. Woltjer concedes that someday general relativity will be important to practical astronomers, but he does not believe that any such bodies (black holes to be precise) are under observation now, and he asserts that conventional astrophysical methods can deal with anything discovered so far.

Gravitational waves are mathematically similar to electromagnetic waves. Both are energy-carrying undulations in space. (Since Michelson and Morley got rid of the "luminiferous ether," it is hard to explain physically what carries the undulation, but a vibration in the transmitter is answered by a vibration in the receiver.)

The energy of electromagnetic waves is generated by accelerations of electrically charged bodies under the influence of electric and magnetic forces. The energy of gravitational waves comes from accelerations of massive bodies under gravitational forces. Both are predicted in the most comprehensive classical theories of their respective subjects, Maxwell's for electromagnetism and Einstein's general relativity for gravitation.

But there are a number of important differences. Electromagnetic waves are easy to transmit and receive once you know how. Gravitational waves are a far weaker effect. The simplest configuration, dipole waves, which are related to vibration in one dimension and which are so widely exploited in radio technology, do not exist for the Einstein gravitational case. The simplest gravitational waves are quadrupole, related to two-dimensional vibrations. They might be produced, for example, by a body pulsing in two dimensions or by a lopsided rotation.

Thus transmitters and detectors for gravitational waves are harder to imagine and engineer than those for radio. The effect of radio waves on charged bodies can be seen against a background of uncharged matter. But all matter is gravitationally charged so it was hard to see what kind of detector could distinguish the passage of gravitational waves. Finally there used to be a certain amount of theoretical naysaying: Some theorists were of the opinion that the solutions to Einstein's equations that predict the waves are, in effect, fictitious solutions, and the things don't really exist. Altogether the conventional wisdom of the general relativistic community was that gravitational waves were a very dubious pot of gold at the end of a very slippery rainbow, and it was better to spend one's life doing other things than looking for them.

In the last 15 years that attitude has been turned almost completely around, and the turning is due largely to the work of Joseph Weber of the University of Maryland and a succession of colleagues and students. Weber figured out a way that gravitational waves could be detected using large metal bars. He convinced himself and others that it would work, and built and operated the antennas. He announced in 1969 at a meeting in Cincinnati and simultaneously in PHYSICAL REVIEW LETTERS that he had detected bursts of gravitational waves.

In the years since, none of those who have come into the field (there are now nearly a dozen experiments in various parts of the world) have managed to confirm Weber's findings, and a certain feeling has arisen that the announcement may have been premature. Whatever history's judgment on that will be, the general feeling now is that it is only a matter of time before gravitational waves are detected in many laboratories and used as aids in astrophysical observation. It is now a respectable thing to ask a government agency for money to build a gravitational wave detector, though how Senator Proxmire would respond if he knew is unpredictable.

The waves, when they are routinely observed, will provide information about the most massive bodies in the universe and the places where the gravitational field is strongest because these are the conditions needed to produce a detectable signal. Each event that one could imagine as a generator of gravitational waves would produce a signal with characteristic frequencies and pulse shape. It is these "signatures" that Thorne wants general relativists to calculate for the various plausible situations.

In spite of changing attitudes about the reality of gravitational waves it is still necessary to convince the astronomical community that the general relativity they belong to is really relevant to astrophysical observations in an important way. Are there enough different objects that gravitational waves might come from and are they important enough to astrophysics to make searches worthwhile?

Thorne begins by remarking that there is strong evidence that we are already in the early stages of observational relativistic astrophysics. The places of application that he sees include, of course, the search for gravitational radiation itself. Confirmation of the existence of the radiation would itself be a major advance. Intellectually, it would parallel Heinrich Hertz's demonstration that Maxwell had not been kidding about the existence of electromagnetic waves. Practically, since there is no way to guide or focus gravitational waves and modulating them would be very expensive in energy, the consequences are likely to go in a different direction—aid to astrophysics.

That is, if the things that produce gravitational waves are really there. Thorne picks out a few situations that ought to be of interest to astrophysicists: the nuclei of galaxies and quasars; the nuclei of supernovas, pulsars and comparable X-ray sources; and the mysterious fluxes of hard X-rays and gamma rays from somewhere in the universe.

Thorne divides the evolution of these objects into three stages: a Newtonian stage, a dynamic relativistic stage, and a quantum relativistic stage. In the Newtonian stage evolution is slow, and conventional methods of observation suffice. In the relativistic dynamic stage, evolution is rapid and general relativity becomes important. The quantum relativistic stage is the hairiest of all, and here even theory has to take the veil because there is not yet a quantized general relativity to deal with it.

It is the dynamic relativistic stage that Thorne thinks observers are beginning to see, and it is these observations that will benefit from gravitational waves. It is the best probe, he says, and he makes the additional point that it is not obscured by dust, as is electromagnetic radiation. There is often a lot of dust around many of the objects cited.

Among the numerous exotica that the dynamic relativistic stage produces, two examples have been much discussed. In the centers of galaxies collisions of massive objects are likely, possibly the crash of two or more black holes. The detailed theory of a two-hole collision is now being worked out—the first of the theoretical projects that Thorne is urging, and it will yield predictions about the gravitational waves such an event will give off.

The latest theorizing also seems to show that black holes are not the static, endless matter and energy sinks that people used to think they were. They can explode (SN: 7/12/75, p. 28). This should yield a very strong gravitational-wave signal.

Collapses of galactic nuclei and of smaller bodies, oscillations and pulsations of massive bodies, all of these are capable of producing detectable gravitational wave signals, and Thorne suggests hypothetical rates of occurrence for such events that make observations look worthwhile. One of his final remarks is: "Gravity waves are the way to go."

Woltjer responds by saying: "I can be very brief. As yet there is effectively absolutely zero connection between relativistic astrophysics and the real world as observed until now." He concedes that the future may change that, but in the same breath asks: "In what sense do you wish, looking at the universe, to see that general relativity is needed?"

The historic example, of course, is Newton's gravitational theory. Woltjer asks if *that* can be deduced from astrophysical evidence. The answer is that Newton's inverse-square law for gravitational forces can be deduced from the behavior of stars and his universal gravitational constant calculated within 10 percent. "I really can say I've got some kind of test for Newtonian laws," Woltjer observes, but, "Nothing in the observed world in that sense requires general relativity except as an esthetic improvement."

He does not deny that general relativity yields "extremely interesting results," but except for the solar system, general relativity and the observed world are not at the stage of comparison of theory and observation. That goes even for the classes of objects cited by Thorne. Woltjer argues that they can all be dealt with by conventional astrophysics.

Thus, while theory and experiment regarding the predictions of general relativity continue, so does the debate over the relevance of the project to the real astrophysical world. It may be that the debate will be overtaken by events, or it may be that there will be no events for a long time. ☐