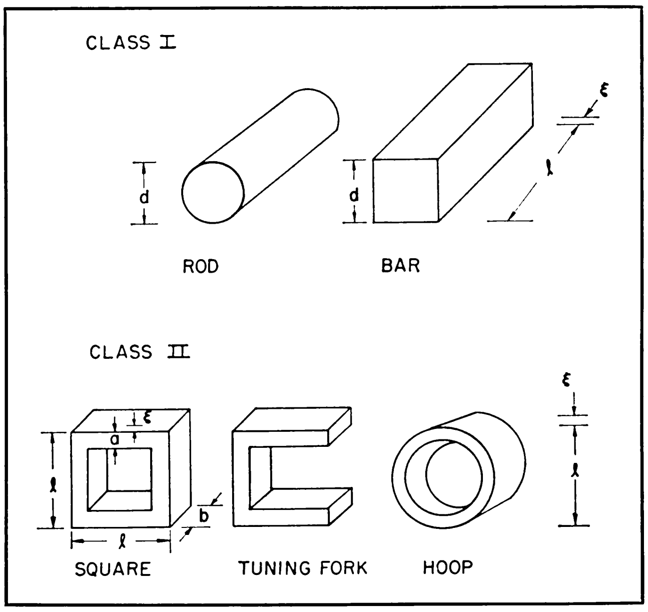
Gaining on gravity waves

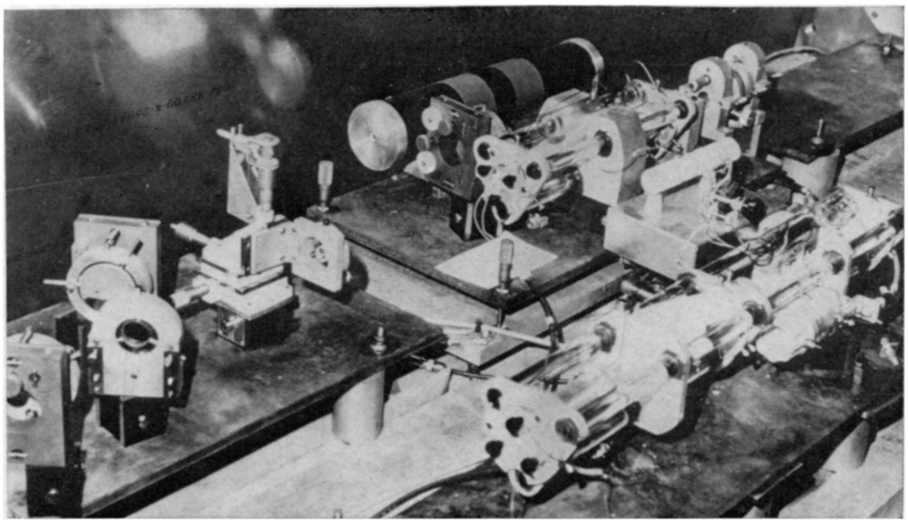
New observers and new techniques join the search pioneered by Dr. Joseph Weber

by Dietrick E. Thomsen



David Douglass

Kinds of narrow-band antennas for gravitational waves.



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Lasers and optical equipment that make Poorman mine a gravity-wave detector.

In 1916 Albert Einstein published his theory of general relativity. In one of its major aspects this is a theory of the nature and operation of gravitational forces with which Einstein intended to replace the classical theory devised by Isaac Newton in the 17th century.

Einstein's theory makes a number of predictions that are radically different from those of Newton. One of the most striking of these is that gravitational forces should be propagated in waves in a manner similar to the way electric and magnetic forces are. These gravitational waves should consist of cyclically fluctuating gravitational forces; they should carry energy from place to place, and they should cause minute fluctuations of the surfaces of objects they encounter.

Any accelerated body could be a source of gravitational waves, but in practice physicists look to large astronomical bodies such as oblate stars or binary stars.

The prediction was that gravitational waves would be extremely weak: For a cylinder a meter long the amount of surface disturbance would be a fraction of the diameter of an atomic nucleus. For 40 years no one seriously looked for gravitational waves, but in the late 1950's Dr. Joseph Weber of the University of Maryland began to develop equipment he thought would do the job. As receivers Dr. Weber uses aluminum cylinders of about a ton's weight, and he has developed piezoelectric sensors that can record fluctuations in the surfaces of these cylinders amounting to fractions of a nuclear diameter.

In 1969, after about 10 years of effort, Dr. Weber announced that his equipment had recorded gravitational waves (SN: 6/21/69, p. 593). Since then he has been subjected to criticism, based mainly on his statistical analysis of the data. Throughout the last year he has maintained that further observations and more rigorous statistics support his original assertion.

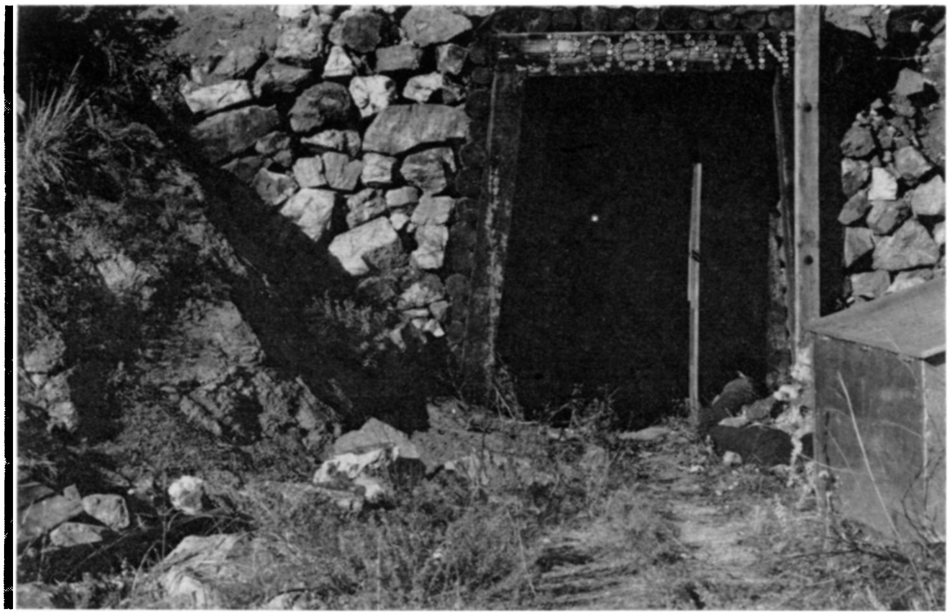
In spite of the critics, confidence in Dr. Weber's work has led other people to enter the search for gravitational waves. About half a dozen experiments are now in progress or in prospect in both the United States and the Soviet Union. Most of these seek to make the detectors more sensitive or to design new kinds of detectors that will record frequency ranges other than the one—1,660 cycles per second (hertz)—that Dr. Weber has pioneered.

Detectors for the waves can be designed either as broad-band receivers that respond to a range of frequencies or as narrow-band receivers that are excited only by a single frequency. Dr. Weber's cylinders are narrow-band receivers.

To supplement the solid-bar type of detector that Dr. Weber used, Dr. David Douglass of the University of Rochester proposes development of a second class of narrow-band receivers, composed of hollow squares, hoops or U-shapes. For this second class of narrow-band receivers he predicts important practical advantages in searches for gravitational wave signals at low frequencies.

Any individual detector of either of these two classes will respond to a particular resonant frequency determined by its size. For the first class of detectors the critical dimension is the length of the bar, and the resonant frequency will be inversely proportional to it. To reach low frequencies extremely long bars would be needed.

For the hollow shapes the critical dimension is the length of a side or a diameter, and the resonant frequency



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A goldmine near Boulder: A hole in the ground can also make an antenna.

turns out to be inversely proportional to the square of this dimension. Under this criterion lower frequencies can be reached with detectors of reasonable size.

To set a limit, Dr. Douglass selected 3 meters as the maximum length of aluminum cylinder that would be mechanically and financially practical to make. With this limit the Class I, solid-body detectors are limited to frequencies above 1,000 hertz. A Class II detector, a hollow square 3 meters on a side, would respond to waves at around 60 hertz.

The Class II limit is particularly important for studies of possible gravitational wave emission by pulsars, particularly the one in the Crab nebula. If the Crab nebula pulsar is radiating gravitational waves, they should come at twice the frequency of its radio pulses, or 60.4 hertz.

Dr. Douglass's Class II detectors have another important advantage: the capability to distinguish between two kinds of gravitational waves proposed by rival theories. Although Einstein's theory is probably the most widely accepted one, a rival has been presented by Drs. Carl H. Brans of Loyola University in New Orleans and Robert H. Dicke of Princeton University.

The Brans-Dicke theory grows out of philosophical considerations that go back to the work of Ernst Mach in the late 19th century. From ideas about what could and could not be real in physical observations, Mach drew the conclusion that the strength of gravitational forces should depend on the amount and distribution of matter in the universe. If this is so, and if the universe, as it expands, spreads the same amount of matter thinner and thinner, then gravity should get weaker as time goes on. Einstein's theory has been a dissatisfaction to followers of Mach because it does not predict this weakening; the Brans-Dicke theory does.

The two theories differ in the nature they ascribe to gravitational forces. Einstein says that gravitational effects are caused by a single kind of force, a so-called tensor force; the Brans-Dicke theory says gravity is a mixture of two kinds of force, Einstein's tensor and a so-called scalar force.

The terms tensor and scalar come from the mathematical entities used to represent the forces in the formulas. One of the physical distinctions between tensor and scalar is in the orientation of the forces in the waves connected to the two varieties. If one imagines a tensor wave proceeding toward the north, at a given point in the cycle, there will be a pair of forces in the vertical direction, one pointing up, the other down. At the same time in the east-west direction will be two forces both pointing in toward the axis of propagation. In a tensor wave all four forces would point away from the axis.

If a tensor wave approached one of Dr. Douglass's hollow squares, two sides of the square would belly out, and two sides would belly in. If a scalar wave came to the same square, all four sides would belly out or in together.

Dr. Weber has an experiment in progress, using a ball and plate instead of a square, by which he hopes to detect a scalar wave if one exists. His latest report covered 22 days of operation during which only tensor waves appeared, but he cautions that the time is really too short to rule out the existence of scalar waves with any confidence.

In the Soviet Union physicists hope to set up an experiment by the end of the year that will repeat Dr. Weber's original work with what they hope will be greater sensitivity, according to a report by Dr. Vladimir Braginsky of Moscow State University. The plan is to use a bar with a square cross-section. The bar will have a trapezoidal groove cut along the top so as "to give it a pair of horns" in Dr. Braginsky's phrase. What they hope to detect is the resonant frequency of the groove as its walls move under the influence of gravitational waves.

Another experiment under consideration by the Russians involves a set of balls and a torsion pendulum. Four balls are placed at the corners of a diamond so that they can respond to gravitational waves going by. Two more balls are suspended from a rod so that they hang in the centers of opposite sides of the diamond. The rod is hung from a wire.

As the corner balls move in and out with the wave, the resulting changes in the gravitational attraction between them and the hanging balls swing the balls and the rod back and forth. The pendulum swings at half the frequency of the gravitational wave.

The device is a broad-band receiver capable of measuring a wide range of frequencies. The Russians are now trying to decide whether to set it up on the ground or in a satellite where it can be more easily isolated from extraneous disturbances.

In Colorado the Joint Institute for Laboratory Astrophysics at Boulder is using a hole in the ground as a resonant cavity for detecting gravitational waves. The hole is a gallery in the abandoned Poorman mine five miles west of Boulder.

The experiment, as Dr. Judah Levine of JILA and the National Bureau of Standards describes it, involves reflecting the light of a laser between two mirrors, one of which is fixed to the end wall of the gallery. The mirrors set up a standing wave corresponding to the resonant frequency of the distance between them. If the end of the gallery moves because of some seismic disturbance, or perhaps a gravitational wave, the resonant frequency of the cavity changes slightly. The laser output adjusts to the new frequency. The changes can be measured by comparing this laser with one not coupled to the cavity, which will have a constant frequency.

The data that Dr. Levine and his colleagues have gathered include a number of natural seismic events and some underground nuclear tests as well as some signals that could be gravitational waves from a pulser that radiates at 30 hertz, but the analysis is too inconclusive for Dr. Levine to make any definite claim yet. ☐