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GRAVITATIONAL ANTENNAS AND THE SEARCH FOR GRAVITATIONAL RADIATION

by

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Introduction

Einstein unified physics and geometry. To understand this new 20th century concept, consider first Euclidean geometry in empty space far from sources of gravitation. A triangle constructed of light rays has sides which are straight lines. The sum of the angles is π radians, Figure 1.

Figure 2 shows the triangle with a gravitating mass inside. The light paths are curved in a gravitational field. The sum of the angles now exceeds π radians. Einstein's unification of geometry and physics was to describe gravitation as spacetime curvature.

Since gravitation is believed to propagate with the speed of light, some kinds of stellar explosions might radiate energy in the form of propagating changes in spacetime — gravitational waves. Figure 3 shows such a wave field.

Gravitational Antennas

Analyses show that for expected sources, the difference between the sum of the angles of light ray triangles and the Euclidean ones is too small to observe with present technology. Two methods were explored at the University of Maryland starting in 1958, and at Hughes Research Laboratories after 1962. These methods give much larger effects than the light ray triangles. One makes use of an elastic solid. The solid changes length when spacetime becomes curved. Figure 4. A second system makes use of a Michelson Interferometer, Figure 5. If the gravitational wave is from a direction normal to the figure, the distance

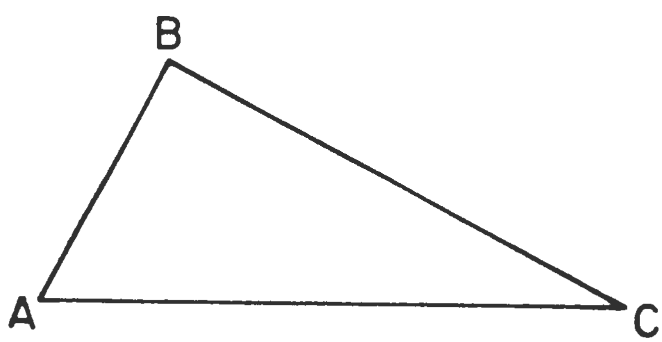


Figure 1. Flat Spacetime

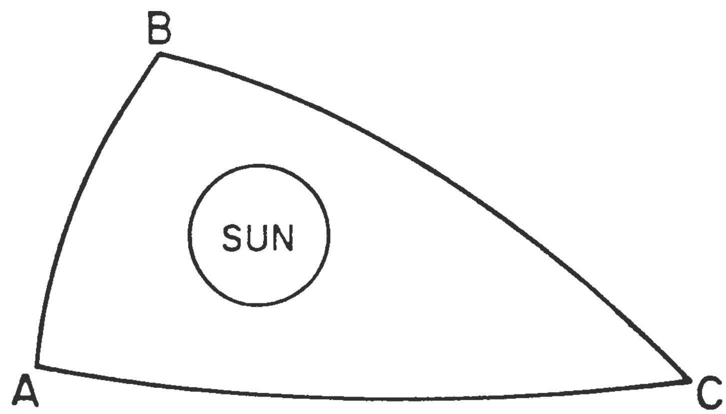


Figure 2. Curved Spacetime

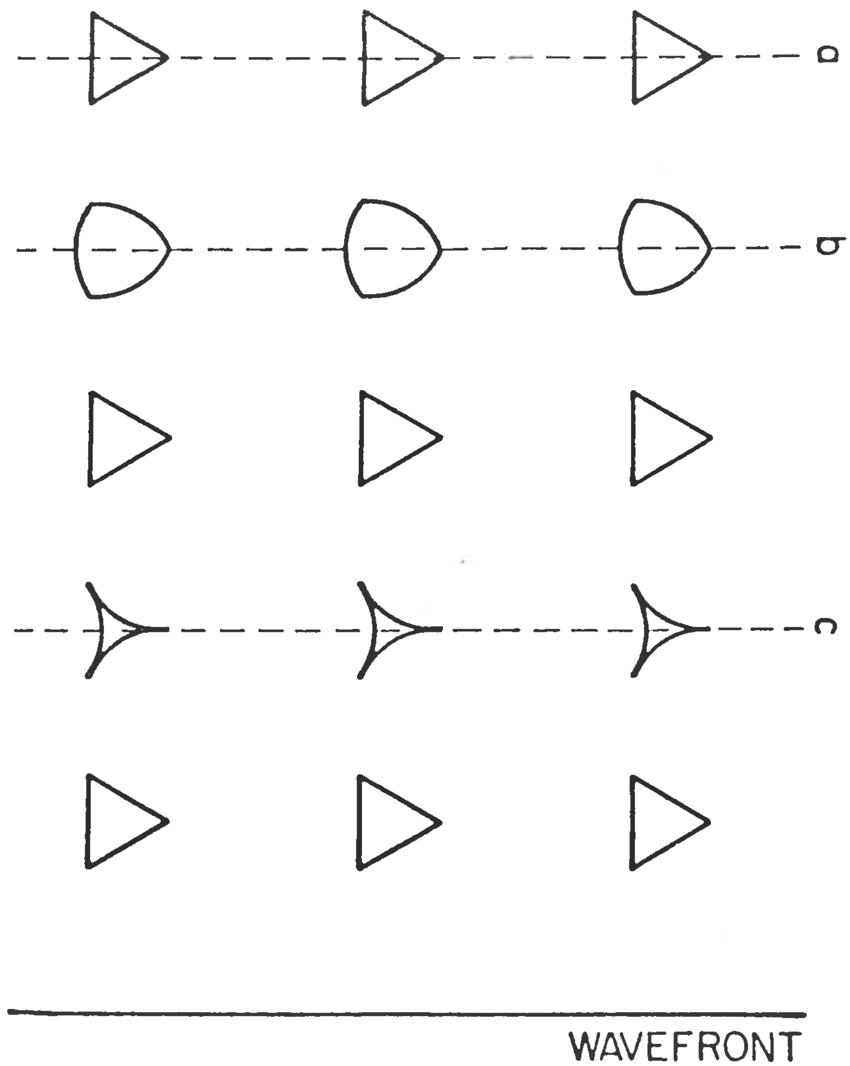


Figure 3. Gravitational Wave Field

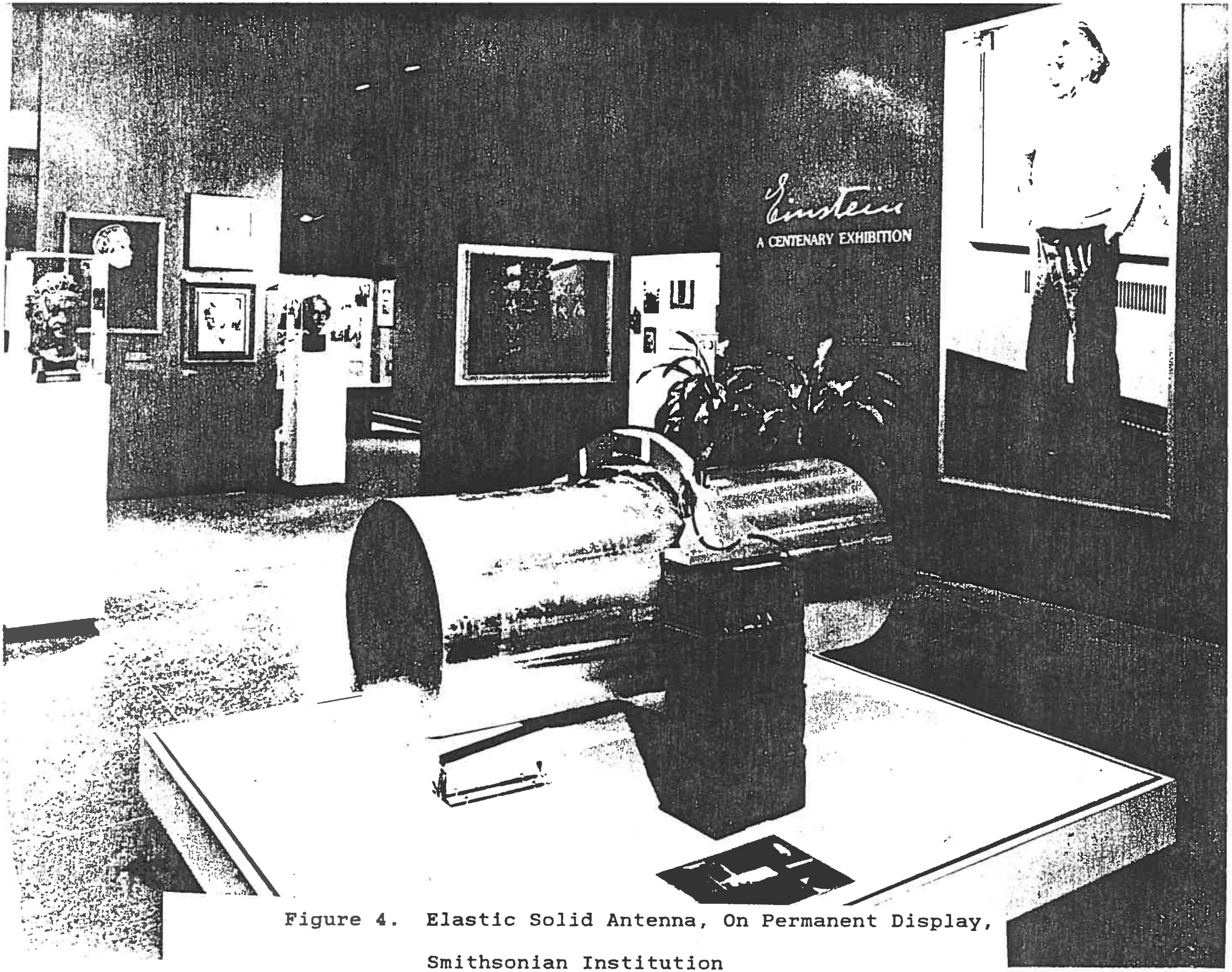


Figure 4. Elastic Solid Antenna, On Permanent Display, Smithsonian Institution

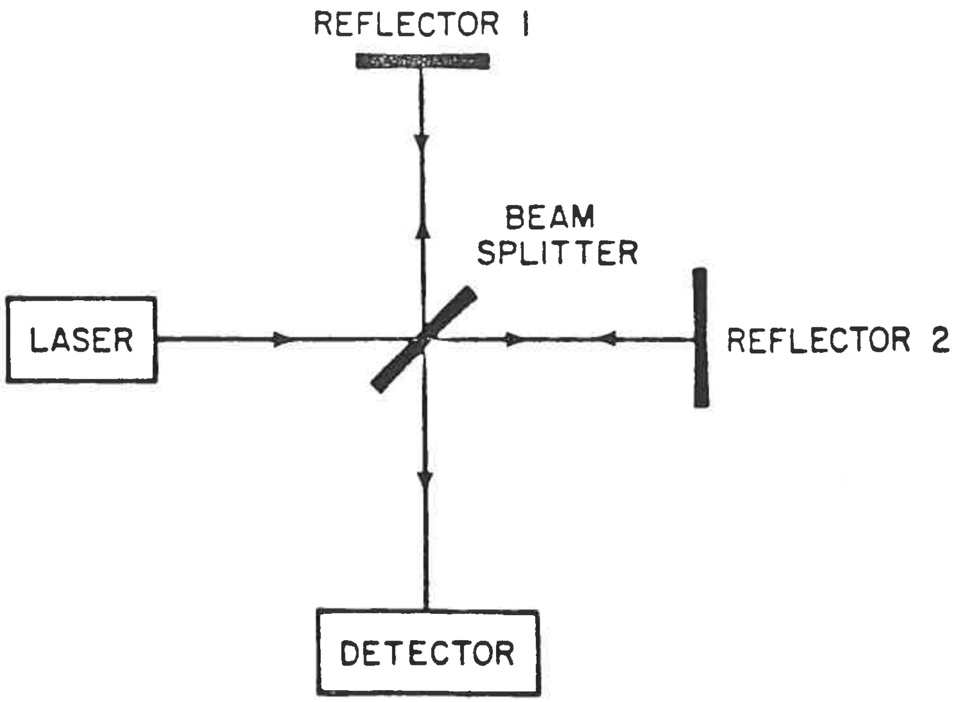


Figure 5. Michelson Interferometer Antenna

between one pair of mirrors may increase at the same time that the distance between the other pair decreases. Changes in optical interference patterns may then be observed.

Ultimate Sensitivity

It was shown by B.S. DeWitt[3] that the elastic solid antenna can measure the spacetime curvature with arbitrary precision. This requires very low temperatures, materials of unusually high quality, careful isolation from earth vibrations, and unusual instrumentation.

Observations

The first elastic solid antennas were developed at the University of Maryland during the period 1959 - 1966. University of Maryland student Dr. Robert L. Forward had been a Howard Hughes fellow who contributed in most important ways to development of the first antenna. After his return to the Hughes Research Laboratory, he developed a very successful Interferometer Antenna.

The early elastic solid antenna could measure changes in length, roughly one hundredth of the diameter of a single atomic nucleus. Instrument outputs corresponding to such changes could result from disturbances other than gravitational waves. For example, lightning striking the building, or trucks colliding with the building do produce signals. To distinguish between local effects and those persisting over large distances, more than one antenna is required. Two antennas were developed, in 1968. One was at the University of Maryland, the other was at the Argonne

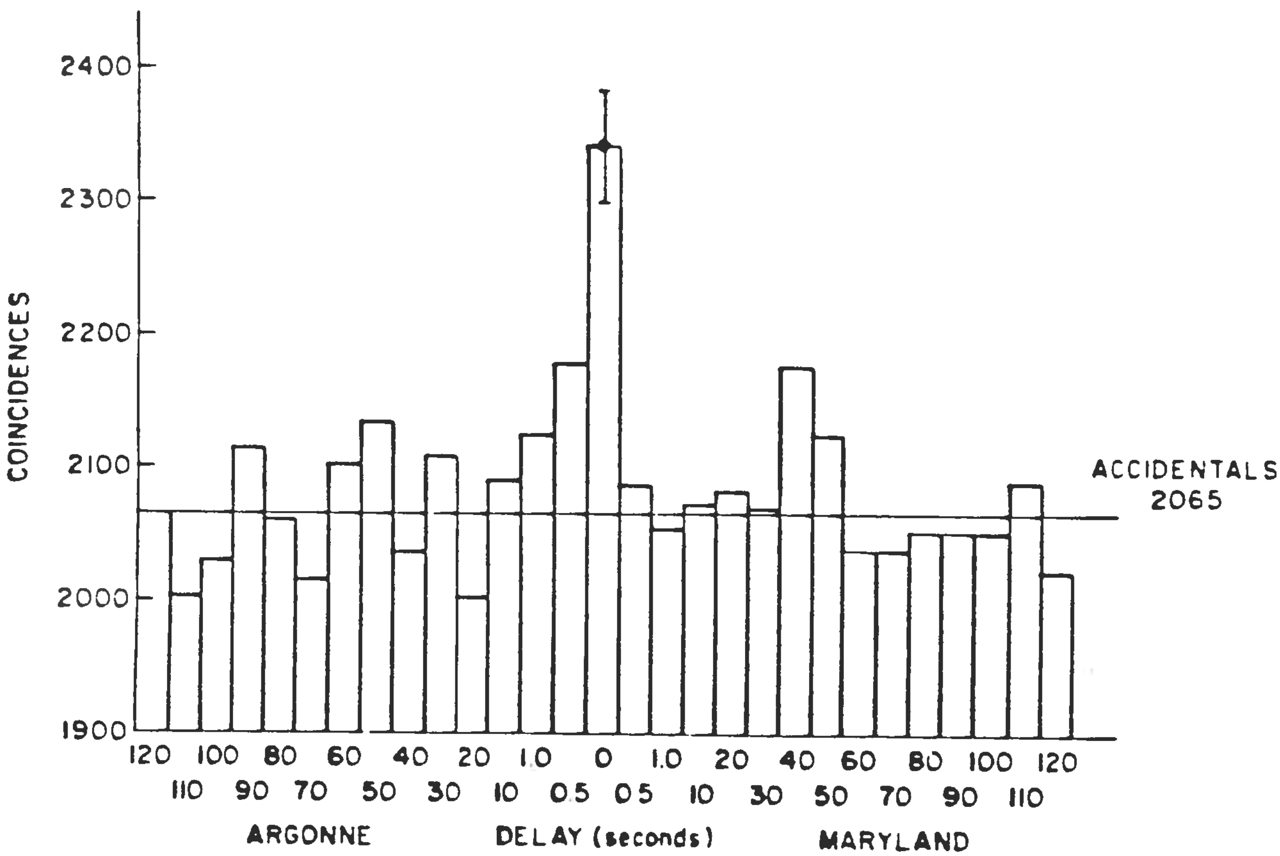
National Laboratory near Chicago. Coincident increases in output were studied.

Two widely spaced antennas will have a certain number of coincidences due to chance alone. Therefore the coincidence experiments are performed in the following way. Records of output versus time are prepared for the two antennas. A computer examines the record, and determines the number of time intervals during which both antennas exceeded some threshold. That is the number of coincident intervals. If the coincidences are due to external signals, the number should diminish if time delays are inserted into one record or the other. The number of coincident intervals for different delays provides a measure of the coincidences due to chance.

Figure 6 is an unusual four day record for the Maryland-Argonne array. With delay zero there are 2335 coincidences. The chance coincidences are smaller — 2065. The zero delay value exceeds the chance coincidences by nearly 6 standard deviations. This is evidence that both antennas are responding to a set of external signals.

Background and Outlook

Observation of statistically significant numbers of coincidences merely proves that the origins are external. A pair of coincident pulses does not carry a label identifying the pulses as gravitational radiation. The situation is similar to what existed with cosmic radiation at the beginning of this century. Careful study and other data are required to identify the sources.



Argonne Maryland Antenna Coincidences With and Without Time Delays 1973

Figure 6. Two Antenna Coincidences

Elastic solid antennas were operating at Maryland and in Rome during supernova 1987A. Pulses were observed within 30 seconds of the Mont Blanc neutrino pulses.

At this time no one knows what fraction, if any, of all the pulses observed between 1965 and the present, are caused by gravitational waves.

References

1. J. Weber, General Relativity and Gravitational Waves, Interscience-Wiley New York London 1961, Chapter 8.
2. R.L. Forward, Applied Optics 10, 2495 (1971), Reference 5.
3. B.S. DeWitt, In Gravitation, An Introduction to Current Research, L. Witten (Ed.) J. Wiley and Sons, New York (1962).

Figure Captions

Figure 1. Flat Spacetime

Figure 2. Curved Spacetime

Figure 3. Gravitational Wave Field

Figure 4. Elastic Solid Antenna, On Permanent Display, Smithsonian Institution

Figure 5. Michelson Interferometer Antenna

Figure 6. Two Antenna Coincidences