GRAVITATIONAL-WAVE-DETECTOR EVENTS*

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A new series of experiments is described, involving two gravitational wave detectors spaced about 2 km. A number of coincident events have been observed, with extremely small probability that they are statistical. It is clear that on rare occasions these instruments respond to a common external excitation which may be gravitational radiation.

Two aluminum cylinders have been instrumented to record the Fourier transform of the Riemann tensor[1-3] in the vicinity of the angular frequency $\omega = 10^4$ rad sec^{-1}. One detector has a diameter of 2 ft, the other has a diameter of 8 in. Both are about 5 ft long. The larger cylinder employs cryogenic electronics and has been employed with a relatively fixed bandwidth $\Delta\omega \approx 0.1$ rad sec^{-1}. The smaller cylinder does not ordinarily employ cryogenics. Its electronics differ from that of the larger instrument in many respects, resulting in electronically adjustable bandwidth over a wide range, and adjustable center frequency.

These detectors are spaced about 2 km. An earlier[3] paper reported observation of coincident events. During the remainder of 1967 roughly one coincidence a month was noted. The relaxation time of these detectors is about 30 sec. Pen-and-ink recorders preceded by circuits averaging over more than the relaxation time were employed. The time resolution was about 1 min.

A gravitational wave detector is a harmonic oscillator driven by the Riemann curvature tensor. The response to a sudden increase in the driving force is a fast rise with decay governed by the relaxation time. It is therefore feasible to resolve signals from the two detectors with precision determined by our ability to resolve the leading edges of the response envelopes.

A two-channel coincidence detector was developed. An average of the envelope is taken over a short interval τ in one channel. If a given threshold is crossed in the positive direction a pulse is generated. Similar functions are performed in the second channel. If the pulses overlap in time an output pulse is generated. Measurements indicated that only pairs of events with leading edges spaced closer than about 0.20 sec generated event-marker pulses. Experiments established that the large detector (with longest relaxation time) required ordinarily less than 0.20 sec between excitation and receiver output. A telephone line joins the small detector to the coincidence apparatus at the large detector site.

Observation of events.—During the past 3 months of operation, events were observed coincident at least to within 0.20 sec. For each coincidence I have listed in Table I the probability and frequency of a random coincidence with the same power. The probability of random coincidences was measured for the last two events listed in the following ways. A chart recorder gives

Table I. Observed coincidences January-March 1968.

Event	(Large-detector power)/mean	No. of large-detector events per day exceeding given power	(Small-detector power)/mean	No. of small-detector events per day exceeding given power	Probability of a random coincidence	Frequency of random coincidence	Date and Greenwich mean time
A	18	Too infrequent to determine by experiment	2.2	43	7.7×10^{-13}	Once in 8000 yr	7 February 2101
B	11	Too infrequent to determine by experiment	2.2	43	1.5×10^{-10}	Once in 40 yr	13 March 1150
C	6	40	2.3	39	8×10^{-9}	Once in 300 d	29 March 0732
D	5	80	2.3	39	1.6×10^{-8}	Once in 150 d	29 March 0358

a record of the number of times a month that each detector output exceeds the value of a recorded coincidence. This enables computation of the probability that each detector will cross threshold during the coincidence resolution time τ. The probability of a random coincidence is the product of the individual probabilities. The theory of stochastic processes was employed to calculate the probability of the rectified envelope crossing a given threshold, as a check on the observations, and as a means of calculating the probability of very rare events such as the first two listed events with a large detector power 18 times the mean and 11 times the mean. The only conclusion which can be drawn about the duration of the events is that they are shorter than the detector relaxation times.

Discussion.—The averaging intervals for the coincidence apparatus are short compared with the relaxation time of each detector. For two such adjacent time intervals the noise outputs in one channel have a high degree of correlation. The probability of a sudden increase is therefore small. A sudden statistical increase in noise, simultaneously in both channels, is extremely unlikely. To generate an event marker both channels must be below threshold during the earlier interval and cross the threshold during the given interval. Of course, if one detector is influenced by local disturbances the probability of coincidences due to random processes at the other detector is no longer extremely small. An elaborate array of seismometers, tilt meters, and electromagnetic recorders is employed to continuously monitor seismic and cultural activity. None of the coincidences recorded here were accompanied by unusual seismic activity. There is a locus of points on Earth which could be an origin for a disturbance propagating, for example, with sound velocity, giving two-detector coincidence for the detectable energy roughly kT. As the resolution time is decreased, fewer and fewer points are included in such a locus. The present resolution time is much shorter than the time associated with sound propagation in Earth or air over the given baseline.

The large detector is very well isolated, by acoustic filtering and shielding, from seismic and electromagnetic disturbances. It is located at a site about a kilometer from ordinary human activity. The smaller detector, for reasons of space limitation, is not so well isolated and its axis had to be nearly normal to that of the large detector. It is located on a concrete pier in a reasonably quiet part of the campus. The directivity is that of a quadrupole. A greater fraction of its output noise is generated in its associated electronics, compared with the large detector, and only a qualitative significance can be attached to the ratio of the two detector responses.

The fact that the earlier event rate is at least maintained as the time resolution is improved more than two orders is very significant. Also significant is the fact that these events are characterized by a large response on the well isolated detector with the larger cross section and a relatively small response on the smaller detector with less isolation from cultural activities. New experiments are in progress with wider detector spacing, search over other frequencies, and bandwidths including pulsar frequencies.

Conclusion.—The extremely low probability of random coincidences enables us to rule out a purely statistical origin. The separated detectors are responding, on rare occasions, to a common excitation which might be gravitational radiation.

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