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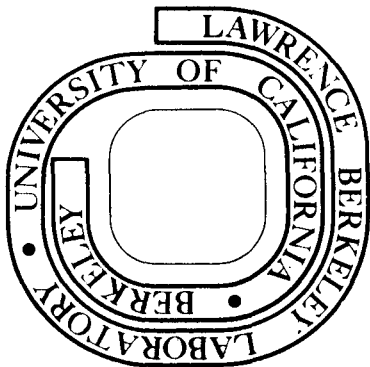1973-10-01

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SEARCH FOR GRAVITATIONAL RADIATION FROM PULSARS[*]

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ABSTRACT

A search for gravitational radiation from pulsars and other periodic radiators was performed using a seismometer and the earth as a detector. The amplified output of a vertical seismometer was sampled, recorded on magnetic tape, and Fourier transformed. Data were collected at two quiet sites in California and searched over the range of 0.1 to 125 Hz both for any signals of narrow bandwidth and for signals at the periods and half periods of 81 known pulsars. No signals were found. Our upper limit on the earth motion due to such signals varies from 10^{-11} meters near 1 Hz to 10^{-14} meters near 125 Hz.

I. INTRODUCTION

In recent years the interest in gravitational radiation has greatly
increased, particularly due to the pioneering work of Weber (1970, 1971,
and 1972). Weber has reported the observation of many signals and has
claimed an excess of signals coming from the direction of the center of
the galaxy. Using coincidence techniques he claims the detection of
single pulses or short bursts of power. His detection scheme however
is not sensitive to periodic gravitational radiation.

With the discovery of pulsars (Hewish, Bell, Pilkington, Scott, and Collins
1968) and the realization that they were massive rotating bodies (Gold 1968) the
first realistic candidates for sources of periodic gravitational radiation were found.
The seismic response of the earth to gravitational waves from pulsars
has been estimated by Weber (1968) and Dyson (1969). They estimate
that the surface displacement of the earth should be about 10^{-19} meters
in response to an energy flux equal in magnitude to that of a star of
bolometric magnitude zero. This is nine orders of magnitude smaller
than ground motion due to microseisms at an optimally quiet site.
Nonetheless, Dyson suggested that a search for such signals would be
worthwhile since the estimates involved several assumptions that could
be wrong by several orders of magnitude. A brief search at the periods
of four pulsars was performed by Wiggins and Press (1969). They saw
no signals and established an upper limit on the earth motion of 10^{-11}
meters. Sadeh and Meidav (1972) reported evidence for gravitational
waves from PS1133; however, more sensitive measurements (Mast,
Nelson, Saarloos, Muller, and Bolt 1972) have seen no signals from that
pulsar with an upper limit of 10^{-12} meters.

We report here on the results of a systematic search for any periodic signals in the earth. Using Fourier transform techniques we have searched the frequency range from 0.1 to 125 Hz. The upper limit was chosen to ensure the possible observation of the Crab Nebula pulsar. Large earth motion at low frequencies limited the usefulness of our search below 0.1 Hz. Because of the directional nature of pulsar signals, only a fraction of the nearby pulsars are detectable by their electromagnetic signals. Hence, it is particularly useful to search at all frequencies rather than simply at those expected from known pulsars.

II. DETECTOR AND OBSERVATIONS

In order to maximize our sensitivity we chose sites with a minimum of cultural and earth-generated seismic noise. Data was collected at the University of California Seismological Station in Jamestown, California and at the Montezuma Mine, Tuolumne County, California. A variable-period vertical seismometer (Sprengnether Model S-7000) was used at both sites. The signal from the seismometer was amplified, passed through a bandpass filter, and sampled at 25 or 250 Hz. The sampled signal was digitized into 6 bits and recorded onto magnetic tape with a Kennedy incremental recorder. To reduce noise from our instruments, the electronics were battery powered and located a few hundred yards from the seismometer. The filter had a sharply defined bandpass. The high-frequency end was set at the Nyquist frequency (half the sampling frequency) to eliminate ambiguities with higher frequencies. The low frequency cutoff of about 0.1 Hz was chosen to eliminate the vast majority of earth noise power and thereby reduce the effect of digitization noise.

A typical run consisted of 2^{20} (about one million) words and lasted about 70 (700) minutes for the 250 (25) Hz sampling. Approximately 100 hours of data were collected. Each run was Fourier analyzed on a CDC 6600 computer using the Cooley-Tukey fast Fourier transform algorithm. The instrumental noise was determined by replacing the seismometer with an equivalent resistance. This noise varied from 25% to less than 1% of the signal. Figure 1 shows the typical smoothed power spectrum measured in the earth (with instrumental noise subtracted) during our runs of maximum sensitivity. The power in meters^2/Hz varies from 1×10^{-9} at 0.1 Hz to 7×10^{-26} at 125 Hz.

The ability of the instrumentation and data processing to detect a signal of narrow bandwidth was proved by the clear observation of a continuous seismic wave of known frequency. A 7-Hz signal was generated with the University of California Shake Table at a distance of 9.9 km from our seismometer and recording equipment. The signal appeared as a strong enhancement in the single expected bin of the Fourier transform.

III. RESULTS

The power spectrum for each run was searched for statistically significant peaks. The statistical significance was based on the excess power in a single bin above a local average of 512 bins. The spectrum from a transform of 2^{20} words sampled at 25 Hz (250 Hz) contains 2^{19} bins each of width 2.4×10^{-5} Hz (2.4×10^{-4} Hz). A signal due to a pulsar-generated gravity wave should occur at a single frequency and should continue to appear in all runs with an amplitude that varies with a 12-hour period. The shape of this 12-hour variation depends on the

position of the source with respect to the rotation axis of the earth.

No such signals were found. Broadband enhancements from instrumental and cultural origin were observed. Some narrow band signals were observed, but these did not appear consistently from run to run. The upper limit (90% confidence level) on the response of the earth to periodic gravity waves is shown as a function of frequency in fig. 2 (solid line). The limits below 12.5 Hz come from a run at Jamestown sampled at 25 Hz. The limits above 12.5 Hz are from a series of 7 runs at Montezuma Mine sampled at 250 Hz. These limits are for signals of unknown frequency. When the frequency of interest is known, then signals of less power become significant and our sensitivity is correspondingly increased. The expected pulsation frequencies of 81 known pulsars (Manchester and Peters, 1972; Manchester and Taylor, 1972; Manchester, Taylor, and Huguenin, 1972; Davies, Lyne, and Seiradakis, 1972) were calculated, taking into account the known pulsar slow-down rates and the Doppler shift due to the motion of the seismometer in the solar system. The power spectra were searched at these frequencies and at twice these frequencies. No significant signals were observed. The limits for the known pulsars are shown as dashed curves in fig. 2.

CONCLUSIONS

No periodic gravitational radiation has been detected down to limits of earth motion as small as 10^{-14} meters. The sensitivity of this experiment was limited by the ability to detect small signals within the intrinsic noise of the earth. An improved signal-to-noise ratio could be obtained by adding coherently the output of independently located seismometers or by collecting coherent data for a longer time. The

useful length of a run is limited by the size of a discrete Fourier transform that can be computed.

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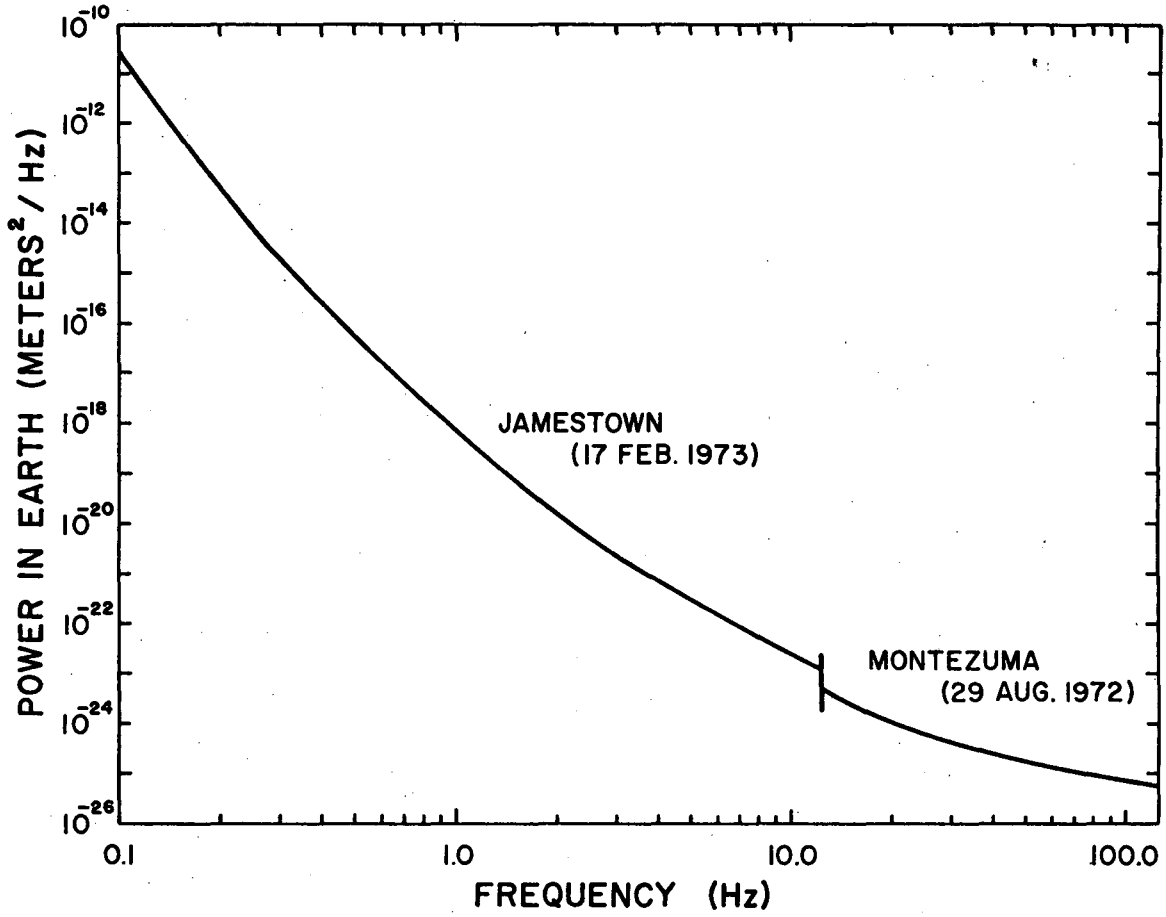
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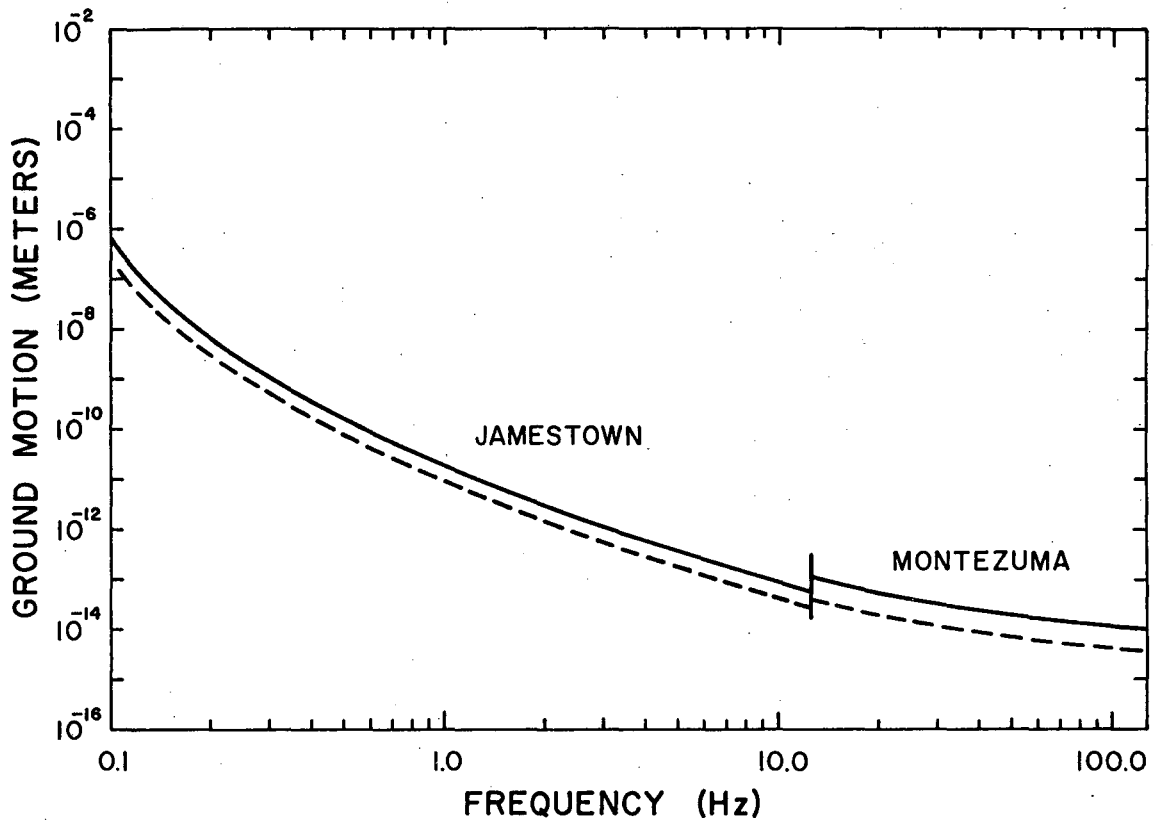Wiggins, R. A. and Press F. 1969, J. Geophys. Res. 74, 5351.

FIGURE CAPTIONS

Fig. 1. Seismic power in the earth (meter^2/Hz) versus frequency measured during the most sensitive runs at Jamestown and Montezuma.

Fig. 2. Upper limit (90% confidence level) on ground motion (meters) due to pulsars as a function of frequency. The dashed curves are the upper limits for the 81 known pulsars referred to in the text.

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