1971

Search for Microwave Pulses Associated with Gravitational Radiation

Bruce Partridge
Haverford College, bpartrid@haverford.edu

1971

Search for Microwave Pulses Associated with Gravitational Radiation

R. Bruce Partridge
Haverford College

Repository Citation
Search for Microwave Pulses Associated with Gravitational Radiation, Physical Review Letters, 26, 912, 1971.

A. van der Woude, Phys. Rev. Lett. 24, 1120 (1970); B. D. Belt, thesis, University of Tennessee, 1970 (unpublished).

[9]J. M. Knight, J. S. O'Connell, and F. Prats, Phys. Rev. 164, 1354 (1967).

[10]I. M. Barbour and A. C. Phillips, Phys. Rev. C 1, 165 (1970).

[11]B. L. Berman, L. J. Koester, and J. H. Smith, Phys. Rev. 133, B117 (1964).

[12]J. R. Stewart, R. C. Morrison, and J. S. O'Connell, Phys. Rev. 138, B372 (1965).

[13]See, for example, G. M. Bailey, G. M. Griffiths, and T. W. Donnelly, Nucl. Phys. A94, 502 (1967).

[14]L. M. Delves and J. M. Blatt, Nucl. Phys. A98, 503 (1967); R. A. Malfliet and J. A. Tjon, Phys. Lett. 30B, 293 (1969).

[15]W. Ebenhöh, A. S. Rinat-Reiner, and Y. Avishai, Phys. Lett. 29B, 638 (1969).

[16]R. J. Slobodrian, J. S. C. McKee, D. J. Clark, W. F. Tivol, and T. A. Tombrello, Nucl. Phys. A101, 109 (1967).

[17]G. Barton, Nucl. Phys. A104, 289 (1967).

Search for Microwave Pulses Associated with Gravitational Radiation*

R. B. Partridge†

Joseph Henry Laboratories, Physics Department, Princeton University, Princeton, New Jersey 08540

(Received 22 February 1971)

A microwave radiometer has been used to search for pulses of radio waves from the the direction of the galactic center. The results were compared with data from Weber's gravitational-wave experiment. No strong evidence was found associating microwave pulses with pulses of gravitational radiation.

In a series of Letters,[1-3] Weber has reported evidence for the detection of pulses of gravitational radiation. In this Letter, we present the preliminary results of an experiment to search for pulses of microwave emission accompanying the gravitational radiation events he observes.

Weber reports that the gravitational radiation arrives in bursts lasting less than 20 sec.[2,4] The characteristic energy flux for a detectable event[1] is 10^4 erg/cm^2 sec in his bandwidth of 0.03 Hz, or

$$E_g \sim 3\times10^5 \text{ erg/cm}^2 \text{ sec Hz}.$$

Events of this magnitude or greater are detected about twice a day. An important feature of his experiment is the directional sensitivity of the apparatus (roughly 70° full width at half-maximum in the main beam[3]) which permits him to search for individual sources. He finds one which he indentifies tentatively with the galactic center.[3] It produces a sidereal time anisotropy which is a six-standard-deviation effect and argues strongly for a nonterrestrial origin for his events—otherwise one would expect the anisotropy in solar time rather than sidereal. His observations imply that very large energy fluxes are involved. If the source of his events is at the galactic center ($d\sim3\times10^{22}$ cm), the total emitted energy for a detectable event is 3×10^{51} erg/sec Hz.

Weber's results are clearly important and need to be checked. To duplicate his experiment is likely to take several years. Last winter, Martin Rees and Remo Ruffini pointed out to me another conceivable check: Look for possible bursts of *electromagnetic* radiation associated with the gravitational-wave events. From several possible sources of gravitational waves, such as catastrophic stellar collapse or rotating neutron stars, one might also expect the emission of some electromagnetic radiation.[5] The collapse of a star with a magnetic field is certain to produce electromagnetic radiation of some sort. The amount and the spectrum of radiation emitted are, of course, open (and important) questions. Nevertheless, the threshold sensitivity of electromagnetic detectors is so much better than that of Weber's detector that we considered a search for electromagnetic emission worthwhile.

In the past year, two experiments to search for pulsed electromagnetic radiation have been carried out, both at radio wavelengths where there is little obscuration of the galactic center. Charman *et al.*,[6] using five spaced receivers at 150 MHz, searched for pulsed radiation arriving in coincidence at two or more receivers. Their receivers were not directional, and they were unable to correlate their results with those of Weber. In addition, the galactic center was above their horizon only for a few hours for most of their runs. They report no indication of signals with a definite extraterrestrial origin.

Experimental details.—The present experiment was planned along quite different lines. The receiver was directional and designed to track the galactic center. I chose to work at a much higher frequency, 19 GHz, where the dispersion delay due to interstellar plasma is negligible (less than 10^{-2} sec for reasonable assumptions about the interstellar electron density). Thus if some event simultaneously produces gravitational and electromatnetic radiation, both should reach Earth simultaneously. My aim was to find the times of arrival of pulses of electromagnetic radiation from the direction of the galactic center and compare these times to the times of arrival of Weber's events. For such a comparison, it is necessary to work at about the same longitude as Weber, so that the galactic center is above the horizon when it is passing through Weber's 70° beam. Princeton, at 75° W, comes close to fulfilling this criterion.

It is most important to stress that with a single receiver I could not eliminate all spurious pulses caused by microwave or intermediate-frequency interference. Thus it is not certain whether an individual microwave pulse originated at the galactic center or not: The value of the experiment lies in what it says about the *microwave flux at the time Weber's events occurred.*

The apparatus consisted of a conventional Dicke radiometer operating at 19 GHz with a nominal bandwidth of 10 MHz. The receiver was alternately switched between the two horn antennas. The main horn with a half-power beamwidth of ~12° tracked the center of the galaxy to an accuracy of ±2°. A smaller reference horn followed a circle of declination +1°, well away from the galactic center. Any bursts of microwave radiation from the galactic center would have appeared as deflections in one direction on a chart recorder. The integration time was 0.3 sec. The instrument was calibrated to an accuracy of better than 3 % at the beginning of each run by terminating the main horn with a blackbody radiator (Eccosorb) at ambient temperature.

Runs normally lasted about 5 h: At the beginning and end of a 5-h run, the galactic center was about 13° above the horizon. For each run, an rms noise level σ was determined visually using two or three sections of the data; for most runs σ was about 2°K antenna temperature. Once σ had been determined, the entire run was scanned, and the position of deflections $\gtrsim 3.5\sigma$ from the mean level were recorded. These were converted to arrival times to an accuracy of ±5 sec by use of timing marks on the chart. On the average, events selected in this fashion occured once every 35 min.

Results.—In this Letter, only the data from $4\frac{1}{2}$ months of spring and summer observations at Princeton will be considered, a total of about sixty 5-h runs. If Weber's events occur at the rate of ~2 per day, then ~25 of his events should have occurred while my experiment was running. In fact the number is 24.

Weber's events fall into three classes: coincidences between a cylindrical detector in Maryland and a similar one at Argonne[3] ("Maryland-Argonne" coincidences); coincidences between two cylindrical detectors both in Maryland ("Maryland-Maryland"); and coincidences between the Argonne cylinder and a new disk detector[7] in Maryland ("Disk-Argonne"). Among the 24 gravitational events recorded by Weber during my runs, *two*, both "Maryland-Maryland" coincidences, occurred within ±30 sec of a microwave pulse (see Table I for a list). To allow for the possibility that interstellar dispersion delayed the microwave pulses, my records were examined for pulses occurring in the interval from thirty seconds *before* a gravitational event was recorded, to ninety seconds *after* it (see Fig. 1). Here the number of coincidences is three. Finally increasing the time interval still further, to ±2 min (approximately eight times the estimated error in the timing measurements) gave a total of six coincidences between Weber's arrival times and mine. The six microwave pulses were in no way different from hundreds of others that I observed.

Now let us estimate the probability that these coincidences between my events and Weber's are accidental. Consider the case for exactly two coincidences among 24 supposedly random events. The probability is given by

$$P_2 = \frac{n(n-1)}{2!}\left(\frac{\Delta t}{\tau_A}\right)\left(\frac{\Delta t}{\tau_B}\right)\left(1-\frac{\Delta t}{\tau_B}\right)^{n-2},$$

where $n=24$. In this equation, Δt is the coincidence time interval and τ is the time between my events. For a coincidence interval of ±30 sec, $\Delta t = 1$ min. From Table I, we find $\tau_A = 22$ min and $\tau_B = 32$ min for the two events under consideration. For the remaining 22 events, I use the mean value $\tau_M = 35$ min. The equation gives $P_2 \simeq 20\,\%$. A similar calculation for the three coincidences within the longer time interval $t_g - 30$ sec $\leq t_{\text{em}} \leq t_g + 90$ sec gives $P_3 \simeq 40\,\%$. Finally, the probability that six accidental coincidences occurred within a coincidence time interval of ±2 min is again about 40 %. It thus seems quite

Table I. Arrival times (EDT.) for gravitational and microwave pulses. Only those events falling within a ±2-min coincidence interval are shown. Note that the observed microwave pulses sometimes precede and sometimes follow gravitational pulses. See text for further explanation.

Gravitational events			Microwave events		
Date	Type	Time of arrival[a] t_g	Time of arrival[b] t_{em}	$t_{em}-t_g$ (sec)	Average time between events, τ (min)
4/11/70	Maryland-Maryland	02:57:50	02:57:30[c]	−20	22
5/31/70	Maryland-Maryland	04:25:36	04:25:18	−20	32
6/1/70	Maryland-Argonne	23:57:40 23:57:50	23:56:47	−60	23
6/6/70	Disk-Argonne	23:45:18	23:47:20	+120	21
6/8/70	Maryland-Argonne (double pulse)	02:28:24 02:28:38	02:27:36 02:29:21	−50 +40	$16\frac{1}{2}$
6/18/70	Maryland-Argonne	02:45:00	02:46:32	+90	27

[a]All ±10 sec. [b]All ±5 sec. [c]A doubtful event in my record.

probable that the coincidences between my events and Weber's are accidental.

In 18 cases, no microwave pulses greater than 3σ appeared within a ±2-min interval about Weber's reported arrival times. Figure 1 displays two of these "negative" cases. *For all 24 events,*

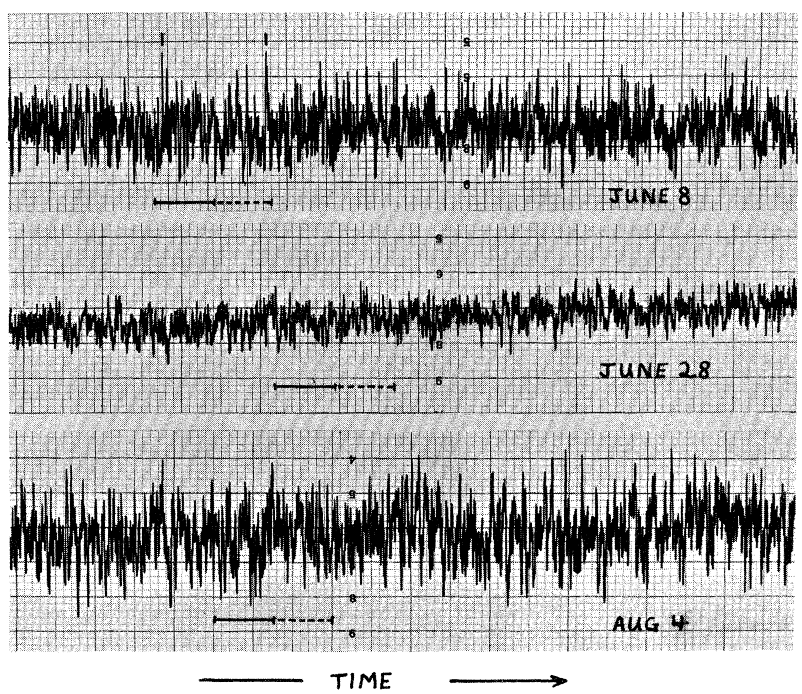

FIG. 1. Three representative chart records. The length of each is ~13 min. The solid horizontal bars indicate 1-min intervals during which Weber reported gravitational events. 1-min intervals following each gravitational event (dashed bars) were also examined for radio pulses. The top record, for 8 June, is one for which microwave pulses exceeding 3.5σ were observed in the interval: The estimated amplitude in each case is 3.7σ. See Table I for the exact arrival times.

a conservative upper limit of 10°K antenna temperature, or

$$E_{em} \lesssim 5\times10^{-17} \text{ erg/cm}^2 \text{ sec Hz},$$

may be set on the flux at 19 GHz. Thus the electromagnetic energy per unit frequency *at this microwave frequency* is approximately 22 orders of magnitude below the gravitational radiation flux, E_g, needed to trigger Weber's detectors. This ratio is of course independent of the assumed distance to the source.

Discussion.—What may we infer from the apparent absence of significant electromagnetic pulses associated with bursts of gravitational radiation? The first point to emphasize is that the spectrum of electromagnetic radiation emitted by a source of Weber's events is completely unknown. Electromagnetic emission could be confined to very low frequencies, or, alternatively, spread over so wide a frequency interval that the energy per unit frequency at 19 GHz is small. Other possible explanations for the absence of strong microwave pulses are these, in ascending order of interest (not necessarily of plausibility!):

(1) The source of Weber's events could lie outside the main lobe of my beam. However, since my instrument had some side-lobe sensitivity, a conservative limit on a source within 30° of the galactic center may still be set very roughly at $E_{em} < 10^{-12}$ erg/cm^2 sec Hz.

(2) The dispersion delay could be 10^4-10^5 times greater than calculated, making it comparable to my event rate. Only if the delay were $\geqslant 10$ min and variable would the correlation between my events and Weber's be lost. A *fixed* delay of up to several hours is being searched for by computer.

(3) Electromagnetic radiation may be emitted over a longer time scale than gravitational. It is clear from Fig. 1 that a significant increase in 19-GHz radiation over time scales $\lesssim 500$ sec following a gravitational event can be ruled out by my data. For longer time scales, up to $\sim 10^5$ sec, very roughly the interval between Weber's events, one can set a conservative upper limit as follows. At 19 GHz, the steady-state antenna temperature of the galactic center is <10°K: Assume that this radiation is *all* due to microwave emission from a single event, spread out over 10^5 sec; then the microwave energy per event is still $\lesssim 5\times10^{34}$ erg/Hz.

(4) Next, 80% or more of Weber's reported events may be accidentals. This possibility leaves his reported sidereal anisotropy unexplained.

(5) A more intriguing possibility is that the sources of Weber's events produce extraordinarily little electromagnetic radiation, or none at all. This question is an important one: For instance, can a "black hole" form in such a way as to emit 3×10^{51} erg/sec Hz of gravitational radiation at 1660 Hz and $\lesssim 5\times10^{29}$ erg/sec Hz in the microwave region?

(6) Finally, and least probably, a fundamental aspect of general relativity may be wrong. No coincidence between my events and Weber's would be expected if the velocity of gravity waves differs from c by more than about 1 part in 10^{10}. Also, if Weber's devices were far more sensitive than he calculates (on the basis of the equation of general relativity),[3] the disparity with my results would be reduced.

A more thorough statistical treatment of both the Princeton data and the newer data obtained at Haverford is in preparation for future publication.

I would like to thank Dr. W. P. Ernst and H. Waage of Princeton for lending me apparatus and D. McCarthy for assisting me with it over the summer. Thanks are also due to R. H. Dicke for his useful comments on the analysis of the results, and especially to M. Rees and R. Ruffini for their initial suggestion to search for radio pulses. I am especially grateful to J. Weber for the interest he has shown in this experiment, for his many helpful comments, for his kindness in providing me with lists of the times of arrival of his events, and for allowing me to include several of them in Table I.

*Research supported in part by the National Science Foundation (at Princeton) and the Alfred P. Sloan Foundation (at Haverford).

†Present address: Haverford College, Haverford, Pa. 19041.

[1]J. Weber, Phys. Rev. Lett. 22, 1320 (1969).

[2]J. Weber, Phys. Rev. Lett. 24, 276 (1970).

[3]J. Weber, Phys. Rev. Lett. 25, 180 (1970).

[4]Or the radiation may have a time-dependent spectrum which sweeps rapidly through Weber's resonant frequency.

[5]R. B. Partridge and R. Ruffini, unpublished.

[6]W. N. Charman, J. V. Jelley, J. H. Fruin, E. R. Hodgson, P. F. Scott, J. R. Shakeshaft, G. A. Baird, T. Delaney, B. G. Lawless, R. W. P. Drever, W. P. S. Meikle, R. A. Porter, and R. E. Spencer, Nature 228, 346 (1970).

[7]J. Weber, to be published.

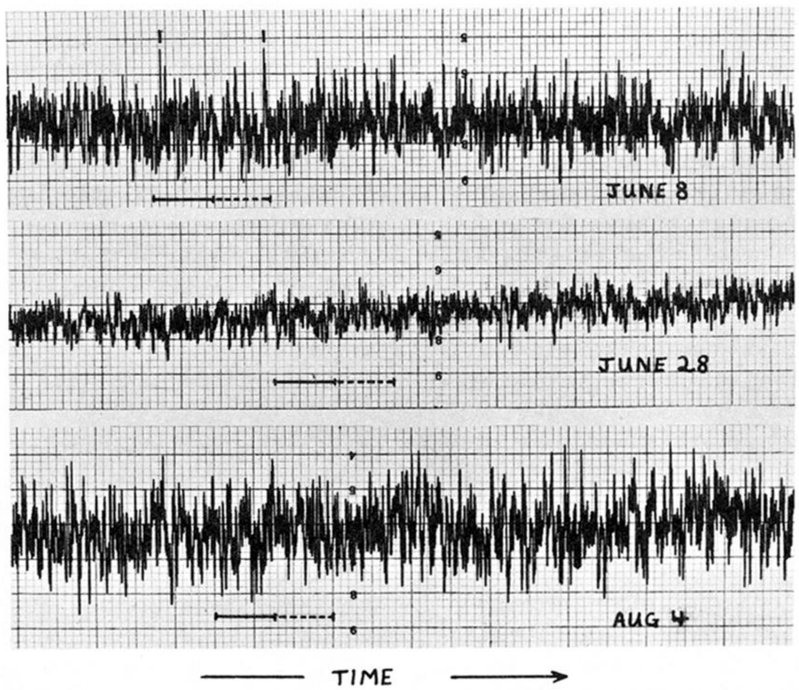

FIG. 1. Three representative chart records. The length of each is ~13 min. The solid horizontal bars indicate 1-min intervals during which Weber reported gravitational events. 1-min intervals following each gravitational event (dashed bars) were also examined for radio pulses. The top record, for 8 June, is one for which microwave pulses exceeding 3.5σ were observed in the interval: The estimated amplitude in each case is 3.7σ. See Table I for the exact arrival times.