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A SEARCH FOR VHF RADIO PULSES IN COINCIDENCE WITH CELESTIAL GAMMA-RAY BURSTS

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ABSTRACT

A detailed search for coincident pulses has been made of VHF radio recordings taken at widely spaced stations around the times of 19 celestial γ-ray bursts between 1970 and 1973. No coincident pulses were found above a sensitivity level of the order of 10^{-12} ergs cm^{-2} (event)$^{-1}$ in a 1-MHz bandwidth.

Subject headings: Gamma-ray bursts — radio sources

I. INTRODUCTION

The recently published information (Strong, Klebesadel, and Olson 1974; Strong 1974) concerning the celestial γ-ray bursts observed by the *Vela* satellites (Klebesadel, Strong, and Olson 1973) has revealed that various portions of their observing period (1967 July 2–1973 June 10) coincided with times during which we were conducting spaced receiver observations in the VHF radio band. These experiments operated mainly at 151 MHz (some stations observed at additional. frequencies down to 43 MHz) and were designed to search for radio pulses which might have been expected during outbursts of supernovae or in association with the pulses reported by Weber (1969). We have therefore searched back through our records around the times of the *Vela* satellite events, allowing liberal figures for the delays and dispersions, for any radio pulses that might be associated with the γ-ray bursts.

II. RADIO OBSERVATIONS

In our first experiments to search for coincident radio pulses at widely spaced stations (Charman *et al.* 1970) the antennas were essentially all-sky viewing. In later experiments directional antennas were added, originally directed toward the galactic center (Charman *et al.* 1971) and later toward the Crab Nebula (Meikle *et al.* 1972). In view of the uncertainties of our sensitivity away from the main beam, together with spatial variations in sensitivity across the interference patterns of our installations, and bearing in mind the uncertainties in the locations of most of the γ-ray events, we searched our data regardless of which antenna system was in use. Furthermore, the search was carried out for all possible γ-ray events, even though in some cases the sources of the bursts may have been below the local horizon at one or more of our stations. A limited search of some of these data and data from other experiments has already been presented by Drever *et al.* (1973).

Throughout the VHF experiments, the integration time was set at 0.3 s, and pulses of up to 100 s were accepted. The lower limit was set by the response time of the recorders, and the upper limit was determined by the motion of sources through the interferometer patterns. Using the usual approximate dispersion relations for a plasma whose critical frequency is much less than the observing frequency, the delay times ΔT, at a mid-band frequency of 151 MHz, consistent with a 100-s dispersion across the receiver bandwidths, $\delta\nu$, are calculated to be 2 and 10 hours, for $\delta\nu = 1$ MHz and 200 kHz, respectively.

Our previous analysis (Charman *et al.* 1970) had failed to yield any convincing evidence for large radio pulses from objects other than the Sun. The Sun, however, produces a copious number of pulses in the VHF band, and hence in general our previous searches were limited to the quieter nighttime hours.

In the present work, where the records are reasonably steady and not subject to excessive solar interference, searches for radio pulses detected in coincidence at two or more stations extended from -1 hr to $+10$ hr

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relative to the γ-ray event times. This search failed to yield any nonsolar radio-radio coincidences.

In addition, the records were searched in detail within ±10 min of the γ-ray event times for any single station pulses. Of the 19 γ-ray events for which some radio data were available, 10 occurred while the Sun was above our horizon and three while it may have been sufficiently high to affect the systems. This left six events which should be clear of any possibility of solar interference. A list of all 19 γ-ray events is given in table 1, together with the results of the single-pulse search. It should be noted that the amount and type of data available varied from event to event so that for some events there were data at more than one frequency from several sites.

It is instructive to break the table down into more manageable sections. In particular, if the events are grouped according to the time of day at which they occurred, then some activity was recorded by one or more stations near nine out of the 10 daylight event times. However, none of the stations recorded any activity within ±10 minutes of five out of the nine night and twilight event times. Near the remaining four night and twilight event times, some activity was recorded by at least one station, but in each case there is evidence that it was not of astronomical origin. Specifically, in the 72–1 event, pulses were observed only at Dublin and Jodrell, while three other stations showed clean records at the time. Moreover, the Jodrell and Dublin records were in general noisy during this period. In the 71–1 event, a Harwell-Dublin coincidence was observed 3 minutes before the γ-ray event time. No pulse was observed on the Glasgow system at this time, and we feel it is unlikely that this twofold coincidence was produced by an astronomical source. In the case of the 72–4 event, only the Glasgow chart showed a pulse near the time; no effects were noted at Cambridge and Dublin. Similarly for the 72–5 event, only the Glasgow record showed a pulse near the event time, while nothing was detected at Cambridge and Harwell.

It is much more difficult to make definitive statements about the daytime records, due to solar interference. However, as already stated, in no case is there a convincing coincident nonsolar radio pulse near the time of a γ-ray burst. A good example of a solar event is 71–5, where a large solar burst (reported in *Solar Geophysical Data*) was observed by our system 8 min before the γ-ray event. It should be noted that not all of the numerous Type III solar bursts are reported in *Solar Geophysical Data*, so that some of our daytime coincidences may not have equivalent pulses registered there. A summary of the solar data is also given in table 1.

The events 71–3, 72–4, and 73–1 are of particular interest in that their directions are sufficiently well established to show that they were above our horizon.

TABLE 1

SEARCH FOR RADIO PULSES WITHIN 10′ OF γ-RAY BURSTS

I	II			III		IV	V	VI	VII	VIII	IX
	Yr	Mo	Day	hr	min						
70–1.....	70	6	14	05	06.9	(solar event)	D	D M̄ Ḡ	D M̄ Ḡ		D very noisy
70–5.....	70	7	10	05	17.8	...	D	D G M̄ H̄	D M̄ H̄ Ḡ	Q	
70–2.....	70	8	22	16	49.5	40°, 83°	D	D̄ Ḡ M̄	D̄ Ḡ M̄	R	
70–3.....	70	12	01	20	00.9	*	N	D̄ Ḡ H̄	D̄ Ḡ H̄	Q	
70–4.....	70	12	30	07	02.3	77°, 95°	N	Ḡ J̄ H̄	Ḡ J̄ H̄	Q	
71–1.....	71	1	02	19	10.9	66°, 122°	N	D Ḡ H	D̄ Ḡ H̄	Q	HD coincidence 3 min before γ burst
71–6.....	71	2	27	17	27.6	...	T	D̄ Ḡ	D̄ Ḡ	Q	
71–2.....	71	3	15	11	20.4	*	D	D Ḡ	D̄ Ḡ	Q	Solar-like noise
71–3.....	71	3	18	15	28.0	45°	D	D̄ G J̄	D̄ Ḡ J̄	Q	
71–4.....	71	4	21	03	18.6	*	N	Ḡ	Ḡ	R	
71–5.....	71	6	30	17	31.0	*	D	D J G C	D̄ J̄ Ḡ C̄	O & R	DJGC coincidence at same time as solar burst
72–1.....	72	1	17	17	39.3	80°, 129°	N	D J Ḡ H̄ C̄	D̄ C̄ J̄ Ḡ H̄	Q	
72–2.....	72	3	12	15	53.3	110°, 71°	D	D J C G H̄	C D̄ J H̄ Ḡ	R	Bursts of pulses at CJD
72–3.....	72	3	28	13	46.5	*	D	D C G H̄ J̄	D C̄ H̄ J̄ Ḡ	R	Bursts of pulses at CD
72–6.....	72	4	27	10	58.5	...	D	C̄ G H̄	C̄ Ḡ H̄	R	Very noisy period
72–4.....	72	5	14	03	46.5	42°	T	D̄ G C̄	D̄ G C̄	O	
72–5.....	72	11	01	18	56.8	50°, 110°	N	C̄ G H̄	C̄ Ḡ H̄	Q	
73–1.....	73	5	07	08	05	52°	D	H̄ C̄	H̄ C̄	O	
73–2.....	73	6	10	21	00	*	T	H̄ C̄	H̄ C̄	O	

NOTE.—Column I gives *Vela* satellite event number. Col. II, date of event. Col. III, event time (UT). Col. IV, approximate zenith angle (degrees) of the γ-ray event (when known) from a point (2°3 W, 53°2 N) near the centroid of the British-Irish network. In many cases alternatives are given. Asterisks indicate that the directions are only defined as being on a circle; dots (...) indicate that no directional data are available (Strong, Klebesadel, and Olson 1974; Strong 1974). Col. V, day (D), night (N), or twilight (T) at the radio sites. Col. VI, code to indicate occurrence of 151-MHz radio pulses within ±10 min of the γ-ray event time. The appearance of a letter in this column indicates a pulse of some sort on the recording from that station. A barred letter, e.g., D̄, indicates a good record but absence of pulses. The absence of a letter generally indicates data were not available from that station. The stations surveyed are: Cambridge (C); Dublin (D); Glasgow (G); Harwell (H); Jodrell Bank (J); and Malta (M). Col. VII, as in col. VI except that only radio pulses within ±1 min of the γ-ray event times are recorded. Col. VIII, solar conditions around γ-ray event times. Q = quiet, O = optical flare reported, and R = radio burst reported (*Solar-Geophysical Data*). Col. IX, comments.

Our records showed no coincident pulses out to the time delays previously mentioned.

In addition to these detailed searches at 151 MHz, the records taken at other frequencies were also examined, with similar negative results.

III. DISCUSSION

It can be argued, in the stellar flare theory (Stecker and Frost 1973), that radio emission may not occur at the same time as the γ-ray bursts. It is well known that in solar flares, while the type III radio and centimeter bursts are associated with hard (>50 keV) X-ray flares, the actual mechanisms involved are quite different (Takakura 1967). It is therefore conceivable that in the magnetic environment of a stellar flare the various processes may take place at different times; there is in fact some evidence that the meter-wavelength radio and optical emissions are not exactly coincident in time even for normal stellar flares (Lovell 1971). However, it seems unlikely that the time separation between γ and radio emissions would be so large as to make our current search invalid.

If the analogy with solar flares is followed further, it appears more reasonable to assume that the number of electrons escaping from the high magnetic field, the γ-ray and centimeter burst-producing region, is simply too small to give a detectable meter-wave burst of the solar type III nature. Takakura (1967) has estimated that in a solar flare which produces hard X-rays and centimeter bursts, about half the electrons must escape into the corona in order for type III emission to occur.

If the failure to detect radio pulses is due solely to dispersion, this is probably confined to the source region, as the dispersion in interstellar and intergalactic space is small compared with the longest delays considered above. A dispersion large enough to give such long delays would require a plasma frequency exceedingly close to 151 MHz over an extensive region, assuming the plasma is nonrelativistic and neglecting magnetic fields.

The simplest conclusion then is that no radio bursts at meter wavelengths are produced at our sensitivity which might reasonably be associated with the γ-ray bursts. Our conservative upper limit for the radio flux at the Earth, taking into consideration the various antenna systems in use, is estimated to be $\sim 10^{-21}$ W m^{-2} Hz^{-1}. Assuming a burst duration of 1 s, this corresponds to an integrated flux of $\sim 10^{-12}$ ergs cm^{-2} (event)$^{-1}$ in the 1-MHz bandwidth of our receivers.

If we were to make the arbitrary assumption of a flat radio spectrum from 151 MHz to zero, and taking a figure $\sim 10^{-4}$ ergs cm^{-2} for the γ-ray flux in a typical burst (Klebesadel *et al.* 1973), our limit would imply that $\leq 10^{-6}$ of the γ-ray energy appears in the form of radio waves.

In any case, our result must place certain constraints on models of the source mechanisms for the γ-ray bursts.

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