shows a cessation of ionosheath flow at radial distances greater than those reported for the ionospheric boundary (*8*). The separation of these two boundaries becomes progressively larger as the sun-Venus-spacecraft angle increases beyond the terminator. This indicates the presence of a cavity on the nightside defined on one side by the inner boundary of the ionosheath and on the other side by the outer boundary of the ionosphere. The inward flow deflections observed thus far, as discussed in connection with Fig. 3, indicate that this cavity is cone-shaped with the cavity closure at times perhaps as close to the planet as about 5 R_V. This result is consistent with the Venera 9 and Venera 10 measurements by Vaisberg *et al.* (*14*) and with other work (*15*).

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Gamma-Ray Burst Observations by Pioneer Venus Orbiter

Abstract. *The Pioneer Venus orbiter gamma burst detector is an astrophysics experiment for monitoring cosmic gamma-ray bursts. It is included in this planetary mission to provide a long baseline for accurately locating the sources of these bursts in order to identify them with specific astronomical objects. Responses to 14 gamma-ray burst events were examined; these events were verified from data acquired by other systems. Preliminary locations are proposed for three events, based on data from the Pioneer Venus orbiter, ISEE C, and Vela spacecraft. These locations will be improved, and additional locations will be determined by including in the analyses data from Helios B and the Russian Venera 11, Venera 12, and Prognoz 7 spacecraft.*

The orbiter gamma burst detector (OGBD) was placed in service about 1 day after the launch of the Pioneer Venus orbiter spacecraft. The instrument thereupon functioned continuously until it was turned off in preparation for orbital injection. After orbital injection the instrument was turned back on, and it has provided continuous observations through the time of this writing.

The OGBD is not truly a participant in the investigations of the planet Venus, but was included to perform astrophysical observations from a platform far removed from Earth. Early in our considerations of the gamma-ray burst (GRB) phenomenon, it became apparent that the identification of GRB sources with other known astronomical objects was of major importance for understanding the mechanisms of generation of these bursts. Since these events occur infrequently and unpredictably, an instrument capable of independently locating the source of each burst with reasonable accuracy and efficiency would need to be massive and complex. Consequently, it was decided to extend the simple locating technique that has been employed with the Vela data (*1*), namely that of triangulation between multiple observing platforms, using time-of-arrival differences between the widely distributed array elements. Clearly, the precision in this technique of location could be improved by simply increasing the separation between members of the array. It was on this basis that the OGBD, which is a modest instrument by the standards of gamma-ray astronomy, was proposed to be included among the complement of the Pioneer Venus orbiter spacecraft.

The OGBD consists of two sensor

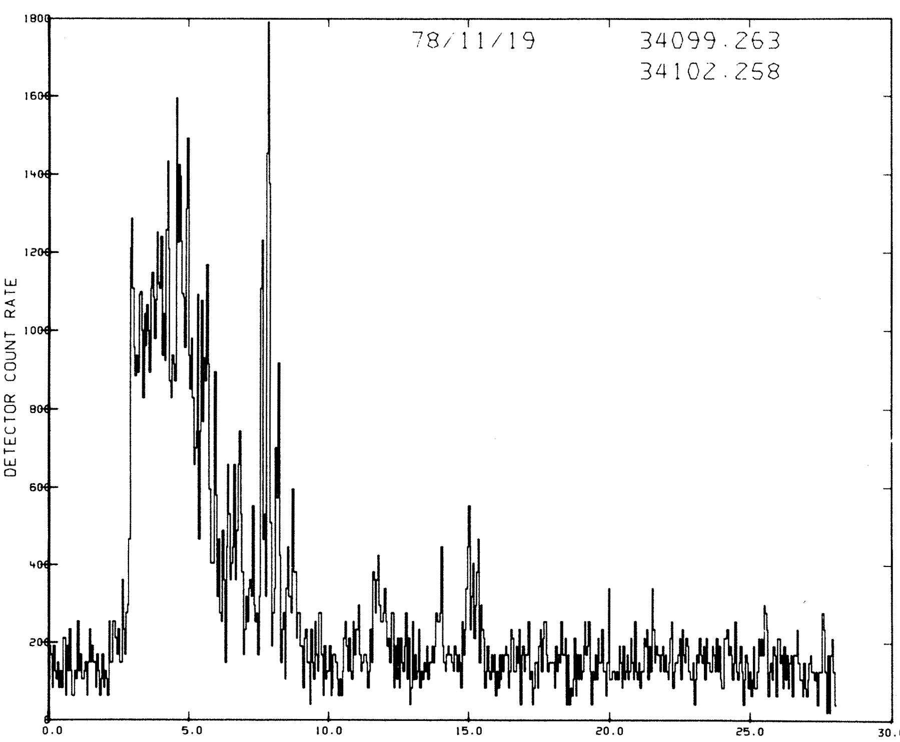

Fig. 1. Event record of 19 November 1978, illustrating the time structure of the count rate in the full energy channel (0.1 to 2.0 MeV) and displaying the entire contents of the experiment memory.

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units and an associated logics package. The sensors are mounted diametrically opposite one another on the equipment platform to minimize the effects of obstruction by the spacecraft. The sensors are CsI scintillation photon counters, 3.8 cm in diameter and 3.2 cm long, sensitive to photons depositing energy in the range 100 keV to 2.0 MeV (nominal). This range is subdivided into four intervals, 100 to 200 keV, 200 to 500 keV, 500 keV to 1.0 MeV, and 1.0 to 2.0 MeV, to provide an indication of the spectral distribution of the signal. The CsI scintillator is actively guarded from direct charged particle interactions through phoswiching, being contained within and optically bonded to a 0.5-cm-thick shell of plastic scintillator.

The electronic logics include a "trigger" function to sense the occurrence of a gamma-ray burst, data formatting, a temporary pretrigger memory (containing ~3 seconds of data), a main experiment memory capable of storing an event record to 28 seconds in duration, state-of-health monitoring, and an independent experiment clock certified to a precision of ~1 msec per day. The trigger logic senses a statistically significant rapid rise in detector counting rate. Data identifying the event, the experiment clock reading, and the contents of the pretrigger memory are then stored in the experiment memory together with data acquired subsequent to the trigger.

During an event, the total number of photons depositing energy within the full range (0.1 to 2.0 MeV) is accumulated on a basic 11.7-msec period. These data are also spectrally analyzed into the four energy subintervals described above, and accumulated for 16 of the basic time intervals, providing spectral analysis with 187-msec time resolution. When the incident photon flux rises to a level sufficient to generate a response of 16 counts in the full energy range in less than the basic 11.7-msec period, the accumulation is truncated. The data mode is then changed to record the time elapsed to accumulate the 16 counts rather than the number of counts accumulated. Data are coded to indicate the mode of operation, avoiding ambiguity. Spectral analyses remain associated with sets of 16 full-range samples.

Table 1. Events recorded by the orbiter gamma burst detector and verified by data from other experiments.

Date	Time (G.M.T.)	Maximum intensity (10^{-5} erg/cm^2-sec)	Fluence (10^{-5} erg/cm^2)
1978			
21 May	21:53:47		~ 5.0
14 September	16:43:48	0.5	~ 1.0
21 September	3:57:02	1.0	1.0
19 October	18:25:58	0.6	1.5
4 November	16:17:05	3.0	10.0
15 November	21:06:42	1.5	1.2
19 November	9:28:22	5.0	10.0
21 November	1:33:57	1.5	3.0
24 November	3:54:00	2.0	1.5
Orbital injection, 4 December 1978			
1979			
13 January	7:33:15	1.0	~ 5.0
5 March*	15:52:05	100.0	~ 10.0
7 March	22:17:34	1.5	10.0
13 March	17:26:36	1.0	2.5
25 March	13:41:33		~ 2.0

*This event has characteristics that set it apart from other gamma-ray bursts that have been observed.

Within 3 hours of being placed into operation, the OGBD recorded its first response to an event, which was soon verified by Vela data as a cosmic gamma-ray burst. Unfortunately, because of the proximity to Earth and the fact that the instrument was not yet properly configured, the source of this event could not be precisely located. During the remainder of the cruise phase of the mission and since injection into orbit, a number of events have been recorded, 14 of which have been verified by data from other experiments and are listed in Table 1.

The experiment has already observed more events than were anticipated for the entire mission. For all except the first event the distance of the Pioneer Venus spacecraft from Earth has been sufficient to provide positional accuracy to better than 1 minute of arc. Also included are several events that rank as the most energetic and the most intense of any gamma-ray bursts observed to date.

Figure 1 is the recorded response of the OGBD to the event of 19 November 1978. The total count rate is displayed as a function of time for the duration of the event record, summed over four time samples to reduce statistical fluctuations. This event is not typical, having a very sharp rise to a high flux level at the start and remaining nearly constant at this high level for more than 2 seconds. A series of brief pulses follow this main pulse, several appearing well after the main pulse has dissolved into the background. A more typical event would exhibit greater variability as a function of time than is seen in the main burst of this event. Most records resemble, in character although not in detail, the gamma-ray burst of 27 April 1972, as recorded by the Apollo 16 gamma-ray spectrometer (*2*).

The modest size of the OGBD instrument restricts its count rate and imposes statistical constraints on our ability to resolve the finer details of time structure for even the more intense bursts. Records of both the event shown in Fig. 1 and that of 4 November 1978 suggest variations occurring on time scales shorter than those resolved here. For example, the event of 4 November contains a single sample 6 msec in duration indicating a count rate of $4 \pm 1 \times 10^3$ sec^{-1} bounded by samples indicating a count rate of $1 \pm 0.2 \times 10^3$ sec^{-1}.

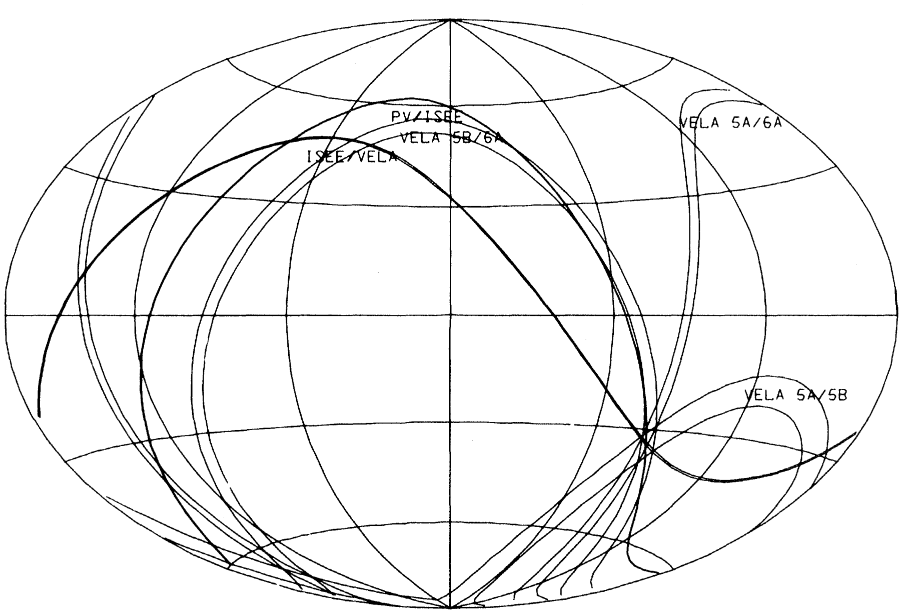

Fig. 2. Calculation of source location illustrated for the event of 5 March 1979, plotted in an Aitoff projection of galactic coordinates, centered at 0°, 0°. The wide error bands are produced by intercomparisons of Vela spacecraft. The unique location of the gamma burst source is at the common point of intersection, $l_{II} = 276°$ and $b_{II} = -33°$, where l_{II} and b_{II} are the galactic longitude and latitude, respectively, referenced to the 1950 coordinate system.

Analyses of the spectral data have not been completed. Here again the low count rates and correspondingly poor statistics have thwarted our efforts to resolve spectral changes, if any, during any of the observed events. All observed spectra appear to be consistent with $dN/dE \sim \exp[-E(\mathrm{keV})/150]$ [where $N(E)$ is the differential photon spectrum and E is the photon energy] as established by IMP 6 and IMP 7 observations (*3*). This spectral signature has been extremely useful in providing tentative identification of the recorded events as genuine gamma bursts.

The primary objective of the OGBD is, as noted above, to assist in the identification of gamma-ray burst sources by improving the resolution of their positional coordinates. The OGBD is incapable of independent directional measurements, being designed to respond omnidirectionally as nearly as possible. It serves its purpose as the member of an array, although a particularly important member because of the distance of separation from near-Earth systems. Other distant members are Helios B, the Russian Venera 11 and Venera 12 spacecraft, and the International Sun-Earth Explorer ISEE C spacecraft with two gamma-ray burst monitors at a distance from Earth of $\sim 1.5 \times 10^6$ km. Vela satellites 5A, 5B, 6A, and 6B, at 1.2×10^5 km, and the Russian Prognoz 7 satellite also provide gamma-ray burst monitoring with time resolution sufficient to be of value in these directional determinations.

Table 2 lists the various spacecraft that observed each of the events listed in Table 1. Additions to Table 2 may be expected since data processing is as yet incomplete, particularly for the more recent events. Events observed by at least four systems will usually yield unique directions, while those observed by three systems will retain an ambiguity (in effect, the mirror image in the plane defined by the three systems). Events observed by only two systems will yield only a circle of position.

Table 2. Spacecraft that observed the events listed in Table 1 and preliminary locations of the sources in equatorial coordinates.

Event	Spacecraft*									Location†	
	HB	VN11	VN12	IC	P7	V5A	V5B	V6A	V6B	RA	DEC
1978											
21 May	X					X					
14 September				X							
21 September		X		X		X					
19 October				X							
4 November			X	X	X	X	X	X	X	301°	−21°
15 November		X	X	X							
19 November	X	X	X	X		X	X	X	X	20°	−30°
21 November			X		X						
24 November	X		X		X	X					
1979											
13 January	X					X					
5 March	X			X		X	X	X		81°	−66°
7 March											
13 March			X								
25 March						X					

*HB, Helios B; VN11 and VN12, Venera 11 and 12; IC, ISEE C; P7, Prognoz 7; and V5A through 6B, Vela 5A through 6B. †RA, right ascension; DEC, declination.

The technique employed for directional determination is illustrated for the event of 5 March 1979 in Fig. 2. The apparent transit time of the signal wave front between two observing platforms relative to their separation establishes the angle of incidence of the wave front relative to the vector defined by the locations of the two platforms. The angle of incidence defines a cone in space, which is represented as a small circle on the celestial sphere. Uncertainties introduce an appreciable width to these circles of position, so that they are more accurately represented as annuli. Simultaneous solution of several such data sets yields an area or areas of uncertainty in which the source object is located.

The uncertainty in each of the directional determinations is proportional to the relative accuracy in the observed transit time of the signal wave front. The absolute accuracy in establishing this transit time is generally limited by the precision possible in comparing the individual records. Thus, the most straightforward means of improving relative transit time accuracy and hence directional resolution, is to increase the baseline for the observations. It may be seen that the width of the directional bands for the Pioneer Venus observations is such that they are represented here as a single line. Ultimate accuracy on the order of 10 seconds of arc will be achieved.

Preliminary locations that could be found by utilizing data from Pioneer Venus, ISEE C, and Vela are listed in Table 2 in equatorial coordinates. These analyses will be extended to include data from the NASA-German Helios B and the Russian Venera 11, Venera 12, and Prognoz 7 spacecraft, improving the definition of the locations.

The three source locations presented here do not lie near the galactic plane. Thus, our original conclusion (*4*) that the sources lie either at distances small compared to the thickness of the galactic disk or at distances great compared to the scale of the galaxy still appears to be valid. Source locations have not yet been sufficiently refined to attempt specific identifications, except for the event of 5 March 1979. The direction of this event is compatible with the Large Magellanic Cloud (LMC), and it will be interesting to see if an identification with a specific astronomical object within the LMC can be achieved.

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