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GAMMA-RAY BURST ARRIVAL TIME LOCALIZATIONS: SIMULTANEOUS OBSERVATIONS BY *PIONEER VENUS ORBITER*, *COMPTON GAMMA-RAY OBSERVATORY*, AND *ULYSSES*

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ABSTRACT

Between the *Compton Gamma Ray Observatory* (*CGRO*) launch in 1991 April and the *Pioneer Venus Orbiter* (*PVO*) demise in 1992 October, concurrent coverage by *CGRO*, *PVO*, and *Ulysses* was obtained for several hundred gamma-ray bursts (GRBs). Although most of these were below the *PVO* and *Ulysses* thresholds, 37 were positively detected by all three spacecraft, with data quality adequate for quantitative localization analysis. All were localized independently to $\sim 2^\circ$ accuracy by the *CGRO* Burst and Transient Source Experiment (BATSE), and three were also localized by COMPTEL. We computed arrival-time error boxes, whose larger dimensions range from about 2′ to several degrees and whose smaller dimensions are in the arcminute range. Twelve have areas less than 10 arcmin^2, and only four have areas greater than 1 deg^2. The area of the smallest box is 0.44 arcmin^2. We find that the overall BATSE localization accuracy for these events is consistent with the most recent stated uncertainties. This work indicates that the *ROSAT* soft X-ray source found within a preliminary IPN error box for GB920501 (Trig 1576) (Hurley et al.) is less likely to be the GRB counterpart than previously reported.

Subject headings: gamma rays: bursts — methods: observational

1. INTRODUCTION

During the years immediately following the discovery of gamma-ray bursts (GRBs), many researchers believed that a few accurate locations would lead quickly to an understanding of the GRB phenomenon. Thus, beginning in the late 1970s, GRB detectors were placed on various interplanetary and solar system probes, achieving interplanetary networks (IPNs) that produced arcminute-sized error boxes calculated by arrival time analysis. While the general optimistic expectations were not realized, accurate locations have continued to be of paramount interest. Applications include deep counterpart searches, archival searches, and error box monitoring, whose purposes are to reveal specific burster counterparts. The recent announcement of a possible GRB optical counterpart with a high redshift (Galama et al. 1997a) perhaps lessens the value of some of these endeavors but raises the possibility of a valuable new use—namely, obtaining individual redshifts for archival bursts by measuring the redshift content of their error boxes. The redshift is essential for quantitative determination of all burst parameters.

In this paper we present quantitative localization information on 37 events that were simultaneously detected by the Burst and Transient Source Experiment (BATSE) on the *Compton Gamma-Ray Observatory* (*CGRO*), *Pioneer Venus Orbiter* (*PVO*), and *Ulysses*. Most of the error boxes are approximately 2–4 orders of magnitude smaller than the best BATSE 3B Catalog (Meegan et al. 1996) localizations. The smallest have areas less than 1 arcmin^2. A few are long and narrow because of unfavorable spacecraft alignments, with the longer dimension being defined by BATSE or COMPTEL boxes. This paper is the second of a series whose aim is to publish essentially all of the accurate and semiaccurate GRB localizations from the IPN. The first paper in this series used *Mars Observer* data (Laros et al. 1997), and the next will present locations for approximately 20 *PVO*/*Ulysses* events that were observed by near-Earth spacecraft other than *CGRO*. Three of the events presented here will also appear in the next paper but with improved localizations (see discussion below and Table 4 notes). The locations are also being archived at HEASARC[1] and at approximately 200 BATSE/*Ulysses* events having larger

[1] Also available at ssl.berkeley.edu/ipn3/index.html

error boxes are included in another catalog (Hurley et al. 1998a).

2. EXPERIMENTAL TECHNIQUE

The *PVO*, BATSE, and *Ulysses* burst detectors have been described elsewhere (Klebesadel et al. 1980; Fishman et al. 1989; Hurley et al. 1992). The localization calculation is straightforward and has been briefly explained in various publications (e.g., Hurley 1994). However, in view of the sometimes controversial history of IPN analysis, a discussion of our experimental technique—particularly the assignment of interspacecraft time delays and their uncertainties—is presented here. We consider both the statistical uncertainties involved in cross-correlating the various data records and the systematics associated with each spacecraft and with the bursts themselves.

Statistical uncertainties are calculated in most cases by the χ^2 analysis described by Hurley (1994) and a similar method developed at Los Alamos for the first IPN and refined at the University of Arizona. (In the 1994 published paper, the square-root symbol was inadvertently omitted from the denominator of the random variable used in the χ^2 summation.) Time delays and their uncertainties are determined independently, with independently developed codes, at the University of California, Berkeley, the University of Arizona, and Goddard Space Flight Center. The results at the three institutions commonly differ slightly—e.g., because of differently selected time binning or intervals, background estimates, or details of the computer codes. In such cases the stated uncertainties are expanded to cover all the error intervals. Occasionally, data gaps or other complications (for example, those brought about by the fact that the three detectors have vastly different sizes and geometries, which leads in some cases to rather different time histories) compromise the functioning of the computer programs, in which case the delays and uncertainties are conservativly estimated by eye. Furthermore, all of the quantitatively obtained results are checked for compatibility with eye estimates.

The gamma-ray detector on *PVO* operated from 1978 May until *PVO* entered Venus's atmosphere in 1992 October. Its ephemeris and timing information is perhaps the best tested of any spacecraft. First, the ephemeris is extremely well known and verifiable (using the Astronomical Almanac) because *PVO* was in orbit around Venus. (Strictly speaking, the Almanac can verify only that the *PVO*-Venus distance is compatible with the *PVO* orbit at the time of each event. *PVO* mission personnel have used the Venus location to validate more accurately the *PVO* ephemeris calculation in general.) For the timing, spacecraft clock word versus UT correlations are available often, and it is clear that the clock is actually far more stable than necessary for the large number of available correlations. Furthermore, the clock correlations, which are provided in a heliocentric frame of reference, immediately reveal the stability of the clock because Doppler shifts caused by Earth-Venus relative motion are absent. We conservatively estimate that any specific clock error greater than about 2 ms would easily have been found. Only small offsets persisting for months or more might have gone undetected. However, overall confidence in *PVO* has been confirmed to the level of several milliseconds over the years by the consistency of redundantly determined error boxes, most notably that of the "March 5 event."

The BATSE timing has been extensively reviewed, partially because of a 2 s error discovered early in the mission. Continuing confidence in the timing is obtained through pulsar timing and other studies. The nominal timing accuracy is 100 μs. However, occasional inconsistencies at the $\sim$1 ms level, probably having to do with the various software systems used, have been found. For a few bursts, the BATSE timing has been confirmed at the 10–100 ms level by *Granat*, *DMSP*, or another near-Earth spacecraft. These considerations and one other (see the second paragraph below on burst spectral variability) have led us to use, in most cases, a 10 ms total systematic uncertainty in the *PVO*/BATSE correlations.

Ulysses timing accuracy can be verified by sending commands to the spacecraft at accurately known times; this is discussed in Hurley & Sommer (1994). In addition, arrival time analysis locations of both classical gamma-ray bursts, the bursting pulsar GRO J1744$-$28, and soft gamma repeaters whose positions are known by independent means have provided a rigorous "end-to-end" test of the timing, spacecraft positions, and the codes used to localize bursts for hundreds of events (see, e.g., Hurley et al. 1996b; Hurley et al. 1997; Galama et al 1997b; Hurley et al. 1998b). Although we have found occasional spacecraft clock errors in the *Ulysses* data records, we believe we have uncovered all of these and that all the uncertainties have been estimated conservatively. However, to be amost completely safe for every event, we have assumed a systematic error $\sim$0.125 s (approximately equal to the accuracy to which the clock can be verified) when correlating to *Ulysses* data.

Another systematic component intrinsic to the bursts themselves has to do with spectral variability and the energy responses of the various detectors. Fortunately, the two lower BATSE discriminator channels are a very good match to the *Ulysses* response, and the two upper channels similarly match *PVO*. Our *PVO*/BATSE and *Ulysses*/BATSE cross-correlations almost always yielded appropriate χ^2 values. The same cannot be said for *PVO*/*Ulysses* correlations because of the minimal energy overlap of the two detectors. However, because the superior BATSE statistical accuracy causes those data to act like a "model" in the analysis, the *PVO*/*Ulysses* cross-correlation uncertainty generally has been estimated as the quadratic sum of the uncertainties in the other two correlations. Thus, spectral variability is not a major concern for these analyses. Nevertheless, when a gamma-ray burst is localized solely by arrival time analysis using a network consisting of fewer than four widely separated spacecraft, the resulting position is not redundantly determined. (Since the BATSE and COMPTEL error circles have dimensions much greater than the annulus widths, they do not provide a stringent test of the localization accuracy.) Therefore, despite the timing accuracy verifications mentioned above, it will never be possible to prove completely and utterly that no additional errors exist. (The same can probably be said of most other experimental measurements.)

3. OBSERVATIONS

Between the *CGRO* launch in 1991 April and the *PVO* demise in 1992 October, concurrent coverage by *CGRO*, *PVO*, and *Ulysses* was obtained for several hundred gamma-ray bursts. Although most of these were below the *PVO* and *Ulysses* thresholds, 37 were positively detected by all three spacecraft. Of the 37, three were independently

TABLE 1

TIMING DATA FOR *PVO*/BATSE/*Ulysses* EVENTS

B Number	Date (yy/mm/dd)	Day of Year	BTIME[a] (UT s)	U − B[b] (s)	P − B[b] (s)	U − P[b] (s)
105	910421	111	33243.756	787.959 ± 0.3	327.268 ± 8.9	460.691 ± 8.9
130	910430	120	61719.147	−1314.268 ± 1.5	−272.1 ± 6.0	−1042.168 ± 6.2
160	910507	127	52275.819	1503.162 ± 2.0	452.080 ± 10.5	1051.082 ± 10.7
219	910522	142	43929.707	−487.514 ± 0.3	−65.444 ± 0.13	−422.070 ± 0.33
394	910619	170	51272.811	965.695 ± 1.0	165.406 ± 4.5	800.289 ± 4.6
451	910627	178	16157.739	−827.870 ± 0.4	−153.619 ± 0.522	−674.251 ± 0.66
543	910717	198	16384.171	880.036 ± 0.3	34.738 ± 0.32	845.298 ± 0.44
548	910718	199	8697.195	382.920 ± 3.0	75.94 ± 3.0	306.98 ± 4.2
678	910814	226	69273.003	1713.930 ± 0.3	122.744 ± 0.04	1591.186 ± 0.3
869	911005	278	27464.811	−741.039 ± 1.0	−22.811 ± 12.0	−718.228 ± 12.0
907	911016	289	39694.187	1842.954 ± 2.0	212.3 ± 7.5	1630.654 ± 7.8
973	911031	304	34580.523	964.452 ± 1.0	106.68 ± 3.0	857.772 ± 3.2
999	911104	308	54281.707	−1590.415 ± 0.3	−240.786 ± 0.094	−1349.625 ± 0.31
1025	911109	313	12457.835	−1138.017 ± 0.3	−114.870 ± 0.091	−1023.146 ± 0.31
1085	911118	322	68258.027	−2146.249 ± 0.3	−347.239 ± 0.188	−1798.985 ± 0.35
1121	911126	330	46127.723	−2431.634 ± 0.4	−333.398 ± 0.446	−2098.240 ± 0.60
1141	911202	336	73729.707	−2099.352 ± 1.0	−376.974 ± 4.8	−1722.378 ± 4.9
1419	920218	49	67342.955	936.185 ± 1.0	165.586 ± 3.3	770.599 ± 3.4
1422	920220	51	46832.235	2166.934 ± 0.5	−508.8 ± 12.0	2675.734 ± 12.0
1440	920226	57	29728.491	606.173 ± 0.3	−405.965 ± 0.084	1012.138 ± 0.312
1468	920308	68	17745.259	−283.316 ± 1.5	239.41 ± 17.5	−522.73 ± 17.6
1473	920311	71	8424.043	−1392.576 ± 0.3	458.114 ± 0.240	−1850.690 ± 0.384
1503	920320	80	44338.859	908.578 ± 0.75	−296.529 ± 6.5	1205.107 ± 6.5
1519	920325	85	62255.915	2004.894 ± 0.3	−731.411 ± 0.043	2736.305 ± 0.303
1533	920331	91	65748.203	624.108 ± 1.0	−18.2 ± 5.0	642.308 ± 5.1
1538	920404	95	47503.979	1938.196 ± 0.3	−596.84 ± 0.47	2534.966 ± 0.56
1541	920406	97	9853.547	1206.530 ± 0.15	−167.468 ± 0.038	1374.004 ± 0.155
1553	920414	105	84161.898	94.281 ± 0.3	3.426 ± 0.06	90.855 ± 0.306
1576	920501	122	76694.634	−1661.302 ± 0.3	143.827 ± 0.071	−1805.129 ± 0.308
1609	920517	138	11874.922	−1332.837 ± 0.3	789.746 ± 0.050	−2122.583 ± 0.304
1610	920517	138	51848.810	−1172.565 ± 2.0	176.190 ± 20.0	−1348.756 ± 20.1
1613	920519	140	59513.962	1592.890 ± 10.0	−189.591 ± 10.05	1782.481 ± 1.0
1625	920525	146	12421.738	1985.323 ± 0.3	455.561 ± 0.075	1529.762 ± 0.31
1695	920711	193	58140.546	295.331 ± 0.3	−81.108 ± 0.098	376.439 ± 0.316
1698	920714	196	47069.314	−809.593 ± .5	244.844 ± 0.4	−1054.437 ± 0.6
1711	920720	202	11524.162	−1722.258 ± 0.3	−370.103 ± 0.059	−1352.155 ± 0.306
1712	920720	202	21172.866	−2914.506 ± 4.0	−704.766 ± 3.0	−2209.740 ± 5.0

[a] BATSE trigger time.
[b] U = *Ulysses* time; B = BATSE time; P = *PVO* time.

localized by *CGRO*/COMPTEL (Kippen et al. 1998), and approximately 20 were also detected by instruments on various other near-Earth spacecraft (see Meegan et al. 1996 comments file for details). If improved localizations result from the non-*CGRO* detections, these will be reported in a separate paper. Table 1 identifies the simultaneously observed GRBs by BATSE Trigger Number (B number), date (year/month/day and day of year), and BATSE trigger time (BTIME) in UT seconds. Also listed are the arrival time delays (geocentric reference frame) and their uncertainties, in seconds, for each spacecraft pair (e.g., "U − B" means (*Ulysses* time minus BATSE time). The listed uncertainties were arrived at by the methods described above. In some cases, the *PVO* and/or *Ulysses* responses are only at the 3–4 σ level, but we have carried out tests—such as comparing spectra, time histories, and intensity ratios among the three spacecraft—that generally give us high confidence in their reality. Geocentric spacecraft coordinates (distance, R.A. and decl.) at the times of observation of each the 37 events are listed in Table 2. Coordinates are J2000, and the distances are in km from the geocenter. Ephemeris uncertainties are generally negligible compared to the other uncertainties unless otherwise noted in Table 2.

4. RESULTS

Tables 3 and 4 list quantitative information on the localizations. Finding charts for several of the events appear in a companion paper to this one (Schaefer et al. 1998). All of the arrival time calculations were carried out independently at the University of Arizona and UC Berkeley, with GSFC participating in the more difficult cases. Table 3 lists J2000 center coordinates—i.e., the direction from the second listed spacecraft (SC2) to the first (SC1)—and radii (inner and outer, in degrees) that define the IPN annuli for the three possible spacecraft pairs for all the events. In Table 4 we give the highest probability point in the error box (essentially, the error box center), the error box area (plane geometry approximation), and the annulus intersections that define the minimum error box. All annulus entries and intersections have been corrected for aberration. It is important for a few of the larger boxes that the intersections be connected by the small circles that define the annuli and not by great circles ("straight lines"). If one uses only great circles, the maximum angular error in radians will be approximately $L^2/(8 \tan R)$], where L is the arc length in radians (i.e., an error box dimension) and R is the radius of

TABLE 2

EPHEMERIS DATA (J2000) FOR *PVO*/BATSE/*Ulysses* EVENTS

B Number	Date (yy/mm/dd)	Day of Year	BTIME	BTIME	*CGRO* Ephemeris[a]	*Ulysses* Ephemeris[a]	*PVO* Ephemeris[a]
105	910421	111	09:14:04	33244	6825. 319.4 − 5.1	413321600. 114.0119 23.3855	167537519. 67.9844 23.7028
130	910430	120	17:08:39	61719	6825. 210.4 17.1	446103468. 116.9185 22.8201	157589918. 79.6596 25.2914
160	910507	127	14:31:16	52276	6824. 254.4 − 24.4	470256779. 119.0983 22.3709	149957528. 88.3009 25.8436
219	910522	142	12:12:10	43930	6822. 117.6 − 12.1	520954541. 123.7977 21.3234	132773963. 106.4886 25.2476
394	910619	170	14:14:33	51273	6820. 80.1 0.3	609090051. 132.5315 19.0781	098881633. 136.1431 18.6244
451	910627	178	04:29:18	16158	6819. 108.0 28.1	630514029. 134.8235 18.4238	089744385. 142.5812 16.0219
543	910717	198	04:33:04	16384	6818. 283.5 17.5	681162510. 140.7054 16.6238	066888778. 154.8178 8.9399
548	910718	199	02:24:57	8697	6818. 303.2 25.5	683224091. 140.9643 16.5407	065939675. 155.1857 8.6302
678	910814	226	19:14:33	69273	6816. 87.5 18.6	735743173. 148.5568 13.9656	044490716. 153.2449 3.3642
869	911005	278	07:37:45	27465	6810. 295.0 − 26.1	772519841. 160.3970 9.5007	072255734. 150.0462 8.8587
907	911016	289	11:01:34	39694	6808. 10.0 18.3	769910307. 162.4431 8.6902	084285019. 158.4982 7.4070
973	911031	304	09:36:21	34581	6805. 28.2 10.5	761224254. 164.7946 7.7534	101005669. 171.8740 3.7644
999	911104	308	15:04:42	54282	6815. 175.0 − 12.3	757818006. 165.3682 7.5249	105762714. 175.9353 2.4605
1025.....	911109	313	03:27:38	12458	6804. 129.2 − 18.4	753730970. 165.9384 7.2984	110877349. 180.3670 0.9338
1085.....	911118	322	18:57:38	68258	6803. 229.1 22.6	743770151. 166.9790 6.8885	121638604. 190.1337 − 2.5494
1121.....	911126	330	12:48:48	46128	6801. 182.3 20.2	734783694. 167.6312 6.6360	130179832. 198.2375 − 5.5423
1141.....	911202	336	20:28:50	73730	6801. 123.2 24.6	726980001. 168.0338 6.4850	137092639. 205.0455 − 8.0151
1419.....	920218	49	18:42:23	67343	6789. 126.2 − 21.7	662483268. 161.9200 8.3863	210121627. 302.4380 − 20.1485
1422.....	920220	51	13:00:32	46832	6789. 254.4 28.4	661640513. 161.5230 8.4286	211463392. 304.7093 − 19.7573
1440.....	920226	57	08:15:28	29728	6787. 290.6 5.1	660059187. 160.2199 8.5689	215800599. 312.1171 − 18.2526
1468.....	920308	68	04:55:45	17745	6778. 200.8 11.7	661933693. 157.7859 8.8218	223468652. 325.6087 − 14.6659
1473.....	920311	71	02:20:24	8424	6784. 181.4 11.2	663476255. 157.1561 8.8824	225397066. 329.1115 − 13.5681
1503.....	920320	80	12:18:59	44339	6782. 312.3 − 2.1	671439467. 155.1857 9.0496	231440831. 340.2835 − 9.6475
1519.....	920325	85	17:17:36	62256	6781. 300.0 10.8	677637195. 154.1778 9.1169	234561958. 346.3253 − 7.3061
1533.....	920331	91	18:15:48	65748	6779. 281.5 20.9	686237057. 153.1053 9.1683	237998573. 353.2664 − 4.4736
1538.....	920404	95	13:11:44	47504	6779. 261.2 23.0	692401819. 152.4836 9.1850	240051279. 357.5763 − 2.6612
1541.....	920406	97	02:44:14	9854	6778. 25.3 − 3.5	695074536. 152.2426 9.1882	240833029. 359.3575 − 1.9099
1553.....	920414	105	23:22:42	84162	6778. 339.1 − 12.0	711732293. 151.0274 9.1641	245161906. 9.3857 2.4123
1576.....	920501	122	21:18:15	76695	6774. 102.3 28.4	748782834. 149.4640 8.9177	252067520. 28.7538 10.4068
1609.....	920517	138	03:17:55	11875	6773. 302.1 17.1	785307550. 148.8928 8.4728	256490259. 46.9643 16.6646
1610.....	920517	138	14:24:09	51849	6773. 23.9 25.2	786431485. 148.8871 8.4561	256618894. 47.5165 16.8359
1613[b].....	920519	140	16:31:54	59514	6772. 220.6 − 14.6	791561399. 148.8692 8.3777	257068768. 50.0826 17.5746
1625.....	920525	146	03:27:02	12422	6772. 219.1 4.6	804737038. 148.8844 8.1584	258083820. 56.9173 19.3430
1695[c].....	920711	193	16:09:01	58141	6767. 240.7 4.7	902240751. 151.9542 5.3203	256156000. 119.684 21.784
1698.....	920714	196	13:04:29	47069	6767. 172.6 − 18.8	906478308. 152.2625 5.1024	255403256. 123.4123 21.1173
1711.....	920720	202	03:12:04	11524	6767. 232.1 25.2	914057406. 152.8910 4.6634	253756108. 130.5557 19.5823
1712.....	920720	202	05:52:53	21173	6767. 145.4 − 13.1	914180983. 152.9022 4.6556	253716266. 130.6879 19.5524

[a] In each cell, the first number is the distance in km s^{-1} and the second and third numbers are geocentric spacecraft coordinates (R.A. and decl.) at the times of observation.

[b] Occultation event. Refined BATSE ephemeris from M. McCollough.

[c] *PVO* ephemeris extrapolated. Accuracy is approximately (1000, 0.001, 0.001).

the annulus (from Table 3). (Any astronomer who is unsure of how to deal with the curvature of the error box edges should contact the authors for assistance. B. Schaefer has also agreed to help with overlays.) As noted in Table 4, some of the boxes are "hybrid"—that is, they use both IPN and BATSE-only or COMPTEL-only localization data. This is necessary when the IPN annuli have a grazing intersection, a condition that can be caused either by the three spacecraft lying close to a single straight line or a burster location that lies close to the plane of the spacecraft. We define a hybrid box to be the intersection of the IPN localization and the 95% confidence BATSE (and, when available, COMPTEL) box. We also note events that will appear in our next paper with localizations that have been improved by inclusion of non-CGRO near-Earth data. Additional information on specific issues and on a significant individual burst is supplied in the sections below.

4.1. *Comparison with BATSE-only Boxes*

For the 31 events with sufficiently small error boxes, we determined the separations between the BATSE locations and the centers of the IPN boxes. The average BATSE statistical location error for these events is only 0.°8, so the BATSE location errors are predominantly due to systematics. Ten events have separation less than 1°, 18 less than 2° and 26 less than 3°, which compares well with the predictions of the BATSE Team's quantitative model of the error distribution (Briggs et al. 1998), which predicts 5.6, 15.9, and 22.8 within these radii. The agreement is not surprising since the error distribution model is based upon a larger data set that included our events. We note, however, that one event (BATSE trigger 1468) has a separation of nearly 11° between the BATSE location and the IPN box center versus the model expected number of 0.09 events past 11° in our set of 31. In general, our results are consistently with the majority of the BATSE locations having systematic errors of approximately 2° but a few having larger errors.

4.2. *GB920501 (BATSE Trigger 1576)*

A preliminary version of this error box, which used ±300 ms for the BATSE/*PVO* uncertainty, was studied by the *ROSAT* satellite (Hurley et al. 1996a). One soft X-ray source was found within the box, at a chance probability <0.01. However, the burst consisted of more than a dozen sharp peaks over a period of about 20 s and can thus be cross-correlated to high statistical accuracy (<20 ms, 3 σ

TABLE 3

IPN ANNULI

B Number	Date (yy/mm/dd)	SC1	SC2	R.A.	Decl.	Rad1 (deg)	Rad2 (deg)
105	910421	BATSE	*Ulysses*	294.0119	−23.3854	55.1333	55.1637
		BATSE	*PVO*	247.9841	−23.7024	53.0233	55.2750
		Ulysses	*PVO*	316.0412	−18.1873	62.9797	64.0821
130	910430	BATSE	*Ulysses*	116.9188	22.8195	27.8406	28.0869
		BATSE	*PVO*	79.6600	25.2902	58.0564	59.5852
		Ulysses	*PVO*	133.0737	18.8247	16.3518	18.5218
160	910507	BATSE	*Ulysses*	299.0959	−22.3715	16.3551	16.8663
		BATSE	*PVO*	268.2961	−25.8437	22.3724	28.0246
		Ulysses	*PVO*	311.3223	−19.1954	22.9018	25.4974
219	910522	BATSE	*Ulysses*	123.7986	21.3236	73.6919	73.7125
		BATSE	*PVO*	106.4886	25.2493	81.4812	81.5152
		Ulysses	*PVO*	129.3048	19.6288	71.3129	71.3432
394	910619	BATSE	*Ulysses*	312.5301	−19.0788	61.5914	61.6555
		BATSE	*PVO*	316.1446	−18.6257	58.9963	60.8036
		Ulysses	*PVO*	311.8281	−19.1584	61.7906	62.1414
451	910627	BATSE	*Ulysses*	134.8255	18.4232	66.8043	66.8280
		BATSE	*PVO*	142.5855	16.0201	59.0030	59.2358
		Ulysses	*PVO*	133.5243	18.7903	68.0658	68.1109
543	910717	BATSE	*Ulysses*	320.7031	−16.6241	67.2062	67.2226
		BATSE	*PVO*	334.8128	−8.9379	80.9638	81.1301
		Ulysses	*PVO*	319.1354	−17.3961	65.7406	65.7675
548	910718	BATSE	*Ulysses*	320.9633	−16.5406	80.2529	80.4059
		BATSE	*PVO*	335.1814	−8.6275	68.9723	70.6377
		Ulysses	*PVO*	319.4132	−17.3212	81.3494	81.5846
678	910814	BATSE	*Ulysses*	328.5535	−13.9668	45.6937	45.7132
		BATSE	*PVO*	333.2483	−3.3631	34.1672	34.2222
		Ulysses	*PVO*	328.2425	−14.6413	46.4287	46.4493
869	911005	BATSE	*Ulysses*	160.3979	9.5004	73.2670	73.3135
		BATSE	*PVO*	150.0437	8.8603	81.7000	87.4331
		Ulysses	*PVO*	161.4608	9.5490	71.8198	72.4372
907	911016	BATSE	*Ulysses*	342.4405	−8.6911	44.0752	44.2034
		BATSE	*PVO*	338.4978	−7.4063	38.5757	43.2444
		Ulysses	*PVO*	342.9264	−8.8461	44.2585	44.8155
973	911031	BATSE	*Ulysses*	344.7938	−7.7537	67.6483	67.6971
		BATSE	*PVO*	351.8751	−3.7640	70.9989	72.0745
		Ulysses	*PVO*	343.7057	−8.3522	67.0246	67.2050
999	911104	BATSE	*Ulysses*	165.3699	7.5244	51.0059	51.0234
		BATSE	*PVO*	175.9378	2.4604	46.9375	46.9792
		Ulysses	*PVO*	163.6555	8.3176	51.8157	51.8364
1025	911109	BATSE	*Ulysses*	165.9398	7.2982	63.0835	63.0988
		BATSE	*PVO*	180.3707	0.9345	71.8938	71.9235
		Ulysses	*PVO*	163.4690	8.3394	61.7291	61.7478
1085	911118	BATSE	*Ulysses*	166.9802	6.8878	30.0953	30.1229
		BATSE	*PVO*	190.1351	−2.5520	31.0976	31.2003
		Ulysses	*PVO*	162.6199	8.5609	31.9283	31.9641
1121	911126	BATSE	*Ulysses*	167.6323	6.6355	7.1243	7.2736
		BATSE	*PVO*	198.2413	−5.5447	39.7521	39.9358
		Ulysses	*PVO*	161.5421	8.9094	1.5474	2.4796
1141	911202	BATSE	*Ulysses*	168.0347	6.4847	29.9886	30.0830
		BATSE	*PVO*	205.0514	−8.0175	33.4008	35.5266
		Ulysses	*PVO*	160.4516	9.2822	34.4006	34.8725
1419	920218	BATSE	*Ulysses*	341.9226	−8.3857	64.9048	64.9621
		BATSE	*PVO*	122.4369	20.1475	76.0545	76.6097
		Ulysses	*PVO*	333.0941	−11.6817	73.8579	74.0035
1422	920220	BATSE	*Ulysses*	341.5278	−8.4262	10.8646	11.0014
		BATSE	*PVO*	304.7145	−19.7576	42.4109	45.2270
		Ulysses	*PVO*	333.1919	−11.5730	16.3194	17.9844
1440	920226	BATSE	*Ulysses*	340.2210	−8.5682	74.0108	74.0270
		BATSE	*PVO*	312.1208	−18.2525	55.6622	55.6784
		Ulysses	*PVO*	333.6149	−11.1863	69.2145	69.2279
1468	920308	BATSE	*Ulysses*	157.7848	8.8220	82.5874	82.6659
		BATSE	*PVO*	145.6085	14.6665	69.8374	72.6785
		Ulysses	*PVO*	154.7687	10.3388	79.4027	80.1002
1473	920311	BATSE	*Ulysses*	157.1525	8.8837	50.9946	51.0146
		BATSE	*PVO*	149.1093	13.5692	52.4358	52.4819
		Ulysses	*PVO*	155.1400	10.0896	51.2553	51.2744
1503	920320	BATSE	*Ulysses*	335.1875	−9.0487	66.0482	66.0902
		BATSE	*PVO*	340.2863	−9.6469	66.8897	67.9347
		Ulysses	*PVO*	336.4922	−9.2089	66.2612	66.5313

TABLE 3—*Continued*

B Number	Date (yy/mm/dd)	SC1	SC2	R.A.	Decl.	Rad1 (deg)	Rad2 (deg)
1519	920325	BATSE	*Ulysses*	334.1816	−9.1151	27.4893	27.5222
		BATSE	*PVO*	346.3313	−7.3046	20.7911	20.8088
		Ulysses	*PVO*	337.3079	−8.6863	25.4114	25.4381
1533	920331	BATSE	*Ulysses*	333.1060	−9.1676	74.1554	74.2074
		BATSE	*PVO*	353.2680	−4.4742	88.3271	89.0490
		Ulysses	*PVO*	338.2970	−8.0536	77.7281	77.9245
1538	920404	BATSE	*Ulysses*	332.4865	−9.1834	32.9340	32.9613
		BATSE	*PVO*	357.5816	−2.6602	41.7596	41.8605
		Ulysses	*PVO*	338.9289	−7.6437	33.7809	33.8187
1541	920406	BATSE	*Ulysses*	332.2451	−9.1874	58.6410	58.6497
		BATSE	*PVO*	359.3579	−1.9094	77.9660	77.9716
		Ulysses	*PVO*	339.1912	−7.4742	63.2394	63.2459
1553	920414	BATSE	*Ulysses*	331.0276	−9.1641	87.7214	87.7359
		BATSE	*PVO*	189.3865	−2.4127	89.7544	89.7628
		Ulysses	*PVO*	340.6696	−6.4770	88.2893	88.3008
1576	920501	BATSE	*Ulysses*	149.4633	8.9181	48.2934	48.3118
		BATSE	*PVO*	208.7516	−10.4058	80.1447	80.1545
		Ulysses	*PVO*	163.2847	4.5215	52.7832	52.7981
1609	920517	BATSE	*Ulysses*	148.8925	8.4728	59.4030	59.4183
		BATSE	*PVO*	226.9606	−16.6627	22.6117	22.6291
		Ulysses	*PVO*	165.0912	2.8012	42.4645	42.4824
1610	920517	BATSE	*Ulysses*	148.8874	8.4561	63.3956	63.4933
		BATSE	*PVO*	227.5159	−16.8353	76.7493	79.4856
		Ulysses	*PVO*	165.1333	2.7491	61.5544	62.4619
1613	920519	BATSE	*Ulysses*	328.8687	−8.3776	52.6263	53.1705
		BATSE	*PVO*	50.0836	17.5748	76.5377	77.9148
		Ulysses	*PVO*	345.3146	−2.5230	51.3701	51.4215
1625	920525	BATSE	*Ulysses*	328.8835	−8.1582	42.2966	42.3156
		BATSE	*PVO*	236.9138	−19.3418	58.0442	58.0560
		Ulysses	*PVO*	345.7073	−1.9554	56.9697	56.9848
1695	920711	BATSE	*Ulysses*	331.9534	−5.3204	84.3665	84.3780
		BATSE	*PVO*	119.6832	21.7835	84.5456	84.5588
		Ulysses	*PVO*	342.2768	0.9217	80.8352	80.8507
1698	920714	BATSE	*Ulysses*	152.2635	5.1023	74.4561	74.4758
		BATSE	*PVO*	303.4095	−21.1184	73.2703	73.3265
		Ulysses	*PVO*	161.6670	−0.9283	63.2886	63.3213
1711	920720	BATSE	*Ulysses*	152.8931	4.6625	55.5974	55.6111
		BATSE	*PVO*	130.5567	19.5810	64.0663	64.0752
		Ulysses	*PVO*	160.3958	−0.8844	54.3623	54.3808
1712	920720	BATSE	*Ulysses*	152.9064	4.6545	16.8448	17.3559
		BATSE	*PVO*	130.6922	19.5520	33.2461	33.9799
		Ulysses	*PVO*	160.3712	−0.8829	17.3994	18.2067

for the BATSE/PVO correlation). The refined error box (specifically, the BATSE/*PVO* annulus) no longer includes the X-ray source. For the BATSE/*PVO* annulus in this paper, we have used a ± 71 ms uncertainty, which includes a 50 ms systematic component and an allowance for a slight difference between the independent UC Berkeley and University of Arizona results. We used 50 ms (not the usual 10 ms) for the systematic error because the only >100 keV BATSE data available for this burst are TTS (time-to-spill), with nonuniform time binning. We believe this is an ample allowance because of the fractional-second widths of most of the peaks. The fact that the *ROSAT* source lies outside the refined box, which is about a factor of 4 smaller than the original, makes it a less likely candidate for a quiescent counterpart. However, in view of the fact that this is not a redundantly determined error box, this possibility cannot be ruled out with absolute certainty.

4.3. *Counterpart Identification Considerations*

We have obtained 12 error boxes with areas <10 arcmin^2. Recent observations of fading optical counterparts make it unlikely that such archival error boxes (except perhaps the very smallest) can yield direct counterparts. However, if the extragalactic interpretation is correct and if the bursters are associated with galaxies (presumedly in clusters), the error boxes can still yield burster distances. Galaxy clusters of ~ 1 Mpc extent at redshifts of 0.1–1 will have angular diameters of $1'$ to a fraction of a degree. Assuming a cluster separation of ~ 10 Mpc, approximately one cluster with $z \sim 0.1$–0.5 will overlap a randomly selected error box with a size of a few arcminutes. Therefore, an error box will typically contain only one cluster (the true association) about one-third of the time, and it will be possible to derive the redshift, hence the distance, of the burst in at least these cases. It will then be possible to reanalyze the burst spectra, time histories, etc., to obtain true source parameters. Thus, it would appear that a project to obtain the redshift content of the smaller IPN boxes has the potential to be tremendously fruitful. In addition, the association of one gamma-ray burst with a radio source that has faded

TABLE 4

ERROR BOX CENTERS, AREAS, AND CORNERS

B Number	Date (yy/mm/dd)	R.A.	Decl.	Area (arcmin^2)
105	910421	269.3756	26.3498	309.
		267.9952	25.6563	
		270.7720	27.0022	
		270.7631	26.9645	
		268.0030	25.6951	
		267.9756	25.6638	
		270.7916	26.9939	
130	910430	135.5958	1.5310	3475.
		137.0524	2.6207	
		134.2027	0.6192	
		134.2335	0.3379	
		137.0348	2.9389	
		137.2485	2.9913	
		134.0347	0.3269	
160	910507	294.4246	−38.4953	10271.
		291.0427	−37.1765	
		297.7609	−39.1993	
		297.4006	−38.6622	
		291.3815	−37.8801	
		290.8962	−37.4349	
		297.8838	−38.9262	
219	910522	138.4143	−51.2489	9.3
		138.4611	−51.2521	
		138.3674	−51.2456	
		138.3337	−51.2722	
		138.4947	−51.2255	
		138.5555	−51.2193	
		138.2730	−51.2782	
394	910619	20.1397	−54.4400	43000.
		20.9010	−38.0191	
		13.7652	−67.7423	
		15.0310	−66.0733	
		21.1077	−40.5321	
		20.8940	−37.2403	
		13.1921	−68.2259	
451[a]	910627	198.92	−3.63	530.
543	910717	247.3703	−58.6640	66.
		247.4875	−59.2052	
		247.2591	−58.1126	
		247.3284	−58.3370	
		247.4138	−58.9874	
		247.4810	−59.2876	
		247.2667	−58.0269	
548	910718	350.9470	60.0416	3900.
		356.8560	58.0564	
		344.7049	61.6163	
		347.5213	60.8328	
		354.2902	59.1261	
		357.7703	57.8453	
		343.7233	61.6940	
678	910814	343.8135	29.2965	139.
		344.4255	29.0772	
		343.2790	29.4813	
		343.5043	29.3878	
		344.1460	29.1948	
		345.2056	28.8168	
		342.7718	29.6208	
869[b]	911005	235.48	14.73	2100.
907[c, d]	911016	298.15	−4.72	5500.
973	911031	284.8800	27.2370	1500.
		286.6304	30.7379	
		283.2889	23.5393	
		283.6175	24.2237	
		286.2462	30.1207	
		286.7016	30.9423	
		283.2344	23.3126	
999	911104	212.2604	35.1971	9.8
		212.2483	35.2464	
		212.2725	35.1479	
		212.2893	35.1607	
		212.2314	35.2336	
		212.2051	35.2948	
		212.3154	35.0993	
1025	911109	111.3321	−27.2475	6.3
		111.3099	−27.2232	
		111.3542	−27.2717	
		111.3419	−27.2844	
		111.3223	−27.2106	
		111.2984	−27.1698	
		111.3657	−27.3251	
1085	911118	166.0568	−23.2078	12.2
		165.9962	−23.2198	
		166.1174	−23.1957	
		166.0882	−23.2226	
		166.0254	−23.1931	
		165.9776	−23.1979	
		166.1360	−23.2175	
1121	911126	160.4009	7.1789	394.
		160.3325	7.2683	
		160.4713	7.0953	
		160.3096	6.7513	
		160.5359	7.7248	
		160.4941	7.7608	
		160.3553	6.7263	
1141	911202	172.7586	−23.1941	707.
		171.6210	−23.3936	
		173.9107	−22.9482	
		173.7281	−23.0788	
		171.8002	−23.2773	
		171.6010	−23.3436	
		173.9318	−22.9972	
1419	920218	37.5534	28.1433	641.
		38.4356	26.3934	
		36.7327	29.6660	
		37.0352	29.0112	
		38.0906	27.2028	
		38.3713	26.5965	
		36.7843	29.5071	
1422	920220	343.2764	2.3671	1911.
		345.2602	1.7812	
		341.4451	2.5750	
		341.6072	2.4381	
		345.0678	1.9937	
		345.2056	1.8738	
		341.4900	2.5070	
1440	920226	270.7269	19.8287	2.1
		270.7457	19.8618	
		270.7081	19.7956	
		270.7394	19.8407	
		270.7144	19.8167	
		270.7223	19.8361	
		270.7315	19.8213	
1468	920308	67.5970	57.9933	5700.
		69.7085	42.2397	
		65.6692	68.3032	
		65.7601	67.0765	
		69.4578	45.1097	
		69.6822	42.9086	
		65.6223	68.0370	
1473	920311	132.1690	−36.3937	15.
		131.9906	−36.3137	
		132.3481	−36.4731	
		132.1533	−36.3975	
		132.1847	−36.3899	
		132.0761	−36.3403	
		132.2621	−36.4469	
1503	920320	323.3904	56.2927	2100.
		313.4302	54.4053	
		333.8554	57.0323	
		331.8824	56.9433	
		315.2196	54.8825	
		313.7863	54.5178	
		333.4529	57.0050	
1519	920325	350.5591	13.0669	4.8
		350.5032	13.0873	

TABLE 4—*Continued*

B Number	Date (yy/mm/dd)	R.A.	Decl.	Area (arcmin^2)
		350.6150	13.0463	
		350.5214	13.0739	
		350.5968	13.0597	
		350.5757	13.0725	
		350.5425	13.0612	
1533	920331	267.3574	29.8174	510.
		266.7752	28.3688	
		267.9527	31.2223	
		267.8217	30.7914	
		266.9004	28.8216	
		266.7880	28.4835	
		267.9388	31.1134	
1538	920404	323.3858	22.5346	14.1
		323.2934	22.4946	
		323.4784	22.5744	
		323.4180	22.5292	
		323.3537	22.5400	
		323.3093	22.5176	
		323.4625	22.5515	
1541	920406	289.0331	−57.5987	0.44
		289.0187	−57.5816	
		289.0475	−57.6158	
		289.0283	−57.5883	
		289.0379	−57.6092	
		289.0292	−57.6016	
		289.0369	−57.5959	
1553	920414	90.4782	−76.2845	0.66
		90.4847	−76.3013	
		90.4717	−76.2677	
		90.4691	−76.2951	
		90.4872	−76.2739	
		90.4985	−76.2810	
		90.4578	−76.2880	
1576	920501	123.8387	−32.7587	0.71
		123.8429	−32.7724	
		123.8346	−32.7451	
		123.8368	−32.7688	
		123.8407	−32.7486	
		123.8453	−32.7537	
		123.8322	−32.7638	
1609	920517	203.3362	−16.6394	3.1
		203.3455	−16.6376	
		203.3270	−16.6412	
		203.3338	−16.6671	
		203.3388	−16.6116	
		203.3485	−16.5902	
		203.3241	−16.6881	
1610	920517	200.8189	58.1093	940.
		202.1247	56.9240	
		199.4021	59.2667	
		199.7038	59.2005	
		201.8503	56.9983	
		202.0395	56.9024	
		199.4916	59.2902	
1613[e]	920519	321.0182	44.0409	260.
		320.1615	43.6515	
		321.8910	44.4173	
		320.2590	43.6650	
		321.7910	44.4064	
		320.1535	43.6768	
		321.8982	44.3921	
1625	920525	300.8674	−42.5713	1.02
		300.8605	−42.5532	
		300.8744	−42.5893	
		300.8692	−42.5593	
		300.8657	−42.5832	
		300.8592	−42.5758	
		300.8757	−42.5668	
1695	920711	281.5166	72.8805	0.92
		281.5245	72.8744	
		281.5087	72.8867	
		281.5545	72.8851	
		281.4786	72.8760	

TABLE 4—*Continued*

B Number	Date (yy/mm/dd)	R.A.	Decl.	Area (arcmin^2)
		281.4663	72.8691	
		281.5669	72.8919	
1698[c, e]	920714	221.0017	−30.1166	570.
1711	920720	202.3449	37.2597	0.87
		202.3512	37.2653	
		202.3386	37.2541	
		202.3462	37.2745	
		202.3436	37.2448	
		202.3480	37.2397	
		202.3417	37.2796	
1712	920720	145.4542	−10.7547	1580.
		145.5853	−11.0979	
		145.3282	−10.4052	
		145.0168	−10.8227	
		145.8982	−10.6772	
		146.0366	−10.8810	
		144.8843	−10.6118	

[a] Hybrid box using BATSE and COMPTEL localizations. Defined by an approximately 6° long segment of the BATSE/*Ulysses* annulus extending 2° north and 4° south of the tabulated position.

[b] Hybrid box using BATSE localization. Defined by a 12°.7 long segment of the BATSE/*Ulysses* annulus centered at the tabulated position.

[c] IPN box is approximately 8° long centered on the tabulated position. No hybrid box is defined because the BATSE 95% confidence location barely overlaps the southern end of the IPN box.

[d] Hybrid box using BATSE and COMPTEL localizations. Defined by a 12°.0 long segment of the BATSE/*Ulysses* annulus centered at the tabulated position.

[e] IPN box to be refined by inclusion of non-BATSE near-Earth data and published in a separate paper.

relatively little after 100 days (Frail et al. 1997) may indicate that even late radio observations could yield significant results.

5. SUMMARY

Using data from *CGRO*, *Pioneer Venus Orbiter*, and *Ulysses*, we computed 37 GRB error boxes whose areas range upward from a fraction of an arcmin^2. Ten have areas less than 10 arcmin^2, and only four have areas greater than 1 deg^2. All the boxes are at least an order of magnitude smaller than the 3B Catalog localizations, whose observed errors are consistent with the claimed BATSE accuracies. We also find that the *ROSAT* soft X-ray source found within a preliminary IPN error box for GB920501 Trigger 1576) appears less likely to be the gamma-ray burster than previously reported. Of course, the true worth of these localizations will be determined by future analyses that result from this and similar publications.

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