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A CATALOG OF GAMMA-RAY BURSTS WITH EARTH CROSSING TIMES

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ABSTRACT

A catalog of 111 confirmed gamma-ray bursts detected between 1967 July and 1979 June is presented. Both localization information and Earth crossing times for the gamma-ray wave fronts are given. Data which have appeared in some previous catalogs have been revised; many previously unpublished events detected by an international network of dedicated deep space and near-Earth experiments since 1976 are also presented.

Subject heading: gamma rays: bursts

I. INTRODUCTION

Although many confirmed gamma-ray bursts have been observed since 1967, no complete catalog exists at present. Partial or preliminary catalogs or lists have appeared (Strong, Klebesadel, and Olson 1974; Klebesadel and Strong 1976; Hurley 1980; Mazets *et al.* 1981), but none of these are complete. Since 1976, an increasing number of interplanetary spacecraft have been equipped with dedicated gamma-ray burst detectors; the limiting positional accuracy of the network which was in operation from 1978 to 1980 has been demonstrated to be on the order of several tens of arc seconds (Cline *et al.* 1982). Data on the time histories, spectra, and precise error boxes of the events detected by this network are believed to warrant separate publication in many cases. The purpose of this catalog (see Table 1) is to provide approximate localization data and Earth crossing times for the gamma-ray wave fronts, which may aid co-workers using radio, atmospheric Cerenkov, spark chamber, or other techniques which do not always require the accuracy needed for complete optical searches. For convenience, some data which have appeared in previous catalogs have been included in this catalog, although, in most cases, the data have been reexamined to include more accurate localizations or Earth crossing times, or both.

II. EVENT CRITERIA AND NOMENCLATURE

An event, in order to be considered a confirmed cosmic gamma-ray burst, must have been detected by at least two instruments on separate spacecraft. Data from the following spacecraft have been searched: *Vela 5A, 5B, 6A*, and *6B; Orbiting Geophysical Observatory 3* and *5; International Monitoring Platform 6* and *7; Orbiting Solar Observatory 6, 7,* and *8: Solrad 11A* and *11B; Helios 2; Prognoz 6* and *7; SIGNE 3; International Sun-Earth Explorer 3; Pioneer Venus Orbiter;* and *Venera 11* and *12* (Franco-Soviet SIGNE experiments). In addition, confirmation of some events has been found in the catalog of Mazets *et al.* (1981). Data from the period 1967 July to 1979 June have been included; for the coverage during this period, see Hurley (1980).

Solar events have been excluded by one or more of the following methods: (1) by arrival time differences at various satellites, (2) by examination of the event time history, (3) by examination of the event energy spectrum, and (4) by lack of solar activity at the time of the observation. This last method is the least reliable and is used only in conjunction with method (2) or (3). Where an event can be localized to a single error box, the nomenclature GBS, followed by the right ascension in hours and minutes and the declination in degrees (e.g., GBS 1144 + 78) is used. For events which cannot be localized to a single error box, the nomenclature GB followed by the year, month, and day of the observation (e.g., GB 691017A) is used, with the letters A, B, and C added where needed to indicate, respectively, the first, second, and third events on this date.

III. EARTH CROSSING TIMES AND ARRIVAL DIRECTIONS

It has been assumed that the events observed consist of plane waves of gamma-rays, i.e., that the source

TABLE 1
GAMMA-RAY BURSTS WITH EARTH CROSSING TIMES

No.	Earth Crossing Time Year	Month	Day	Seconds	Uncertainty[a] (s)	Name	References	Localization
1	1967	Jul	2	51568	3	GB 670702	1, 2	...
2	1969	Jul	3	26233	...	GB 690703	1, 2, 3	R.A. = 191, decl. = +20, R = 27 (3.5)
3	1969	Jul	19	13604	...	GB 690719	2	...
4	1969	Oct	7	26790	...	GB 691007	1, 2, 3, 4	R.A. = 236, decl. = +33, R = 50(5)
5	1969	Oct	8	59442	...	GB 691008	...	...
6	1969	Oct	17	11927	...	GB 691017A	1, 2	R.A. = 102, decl. = −27, R = 86(2)
7	1969	Oct	17	78113	...	GB 691017B	1, 2, 3	R.A. = 156, decl. = +1, R = 83(2)
8	1970	Jan	25	18090	...	GB 700125	5	See Ref. 5.
9	1970	Jul	10	19066	...	GB 700710	1, 2	...
10	1970	Aug	22	60569	...	GB 700822	1, 2, 3	R.A. = 142, decl. = +62 or R.A. = 210, decl. = −29(3)
11	1970	Oct	1	56530	...	GB 701001	2, 5	See Ref. 5.
12	1970	Dec	1	72059	...	GB 701201	1, 2, 3	R.A. = 91, decl. = −29, R = 68(3)
13	1970	Dec	30	25337	...	GB 701230	1, 2	R.A. = 96.6, decl. = −28.9, R = 44.4(3)
14	1971	Jan	2	69056	...	GB 710102	1, 2, 3	R.A. = 176, decl. = +40 or R.A. = 194, decl. = +5(5)
15	1971	Feb	27	62854	...	GB 710227	1, 2	...
16	1971	Mar	15	40827	...	GB 710315	1, 2, 3, 6	R.A. = 4, decl. = −21, R = 82(See Ref. 3.)
17	1971	Mar	18	55685	...	GB 710318	1, 2, 3, 6	R.A. = 69, decl. = +12 or R.A. = 115, decl. = −71(3)
18	1971	Apr	21	11919	...	GB 710421	1, 2	R.A. = 247, decl. = +34, R = 81(3)
19	1971	Jun	30	63059	...	GB 710630	1, 2, 3, 6	R.A. = 207, decl. = +30, R = 67(2)
20	1972	Jan	17	63556	...	GB 720117	1, 2, 6	R.A. = 322, decl. = +50 or R.A. = 262, decl. = −16(5)
21	1972	Mar	12	57194	...	GB 720312	1, 2	...
22	1972	Mar	28	49587	...	GB 720328	1, 2, 6	R.A. = 283, decl. = +22, R = 11(11)
23	1972	Apr	27	39512	...	GB 720427	1, 2, 7	See Ref. 7.
24	1972	May	14	13591	...	GBS 1144+78	1, 2, 6, 8	R.A. = 176, decl. = +78(3)
25	1972	Nov	1	68206	...	GB 721101	1, 2	R.A. = 11, decl. = +19 or R.A. = 305, decl. = −48(3.5)
26	1972	Nov	13	57758	9	GB 721113	2, 6	...
27	1972	Dec	18	73659	...	GB 721218	2, 6, 9, 10	R.A. = 020, decl. = −33, R = 70(5)
28	1973	Jan	25	54910	9	GB 730125	2, 6	...
29	1973	Mar	2	84475	...	GB 730302	2, 6, 10	R.A. = 59, decl. = 59 or R.A. = 211, decl. = −47(8)
30	1973	Apr	16	45553	9	GB 730416	2, 6	...
31	1973	May	7	29071	...	GB 730507	1, 2, 10	R.A. = 342, decl. = +56 or R.A. = 254, decl. = −33(3.5)
32	1973	Jun	6	25648	...	GB 730606A	2, 6, 10	See Ref. 10.
33	1973	Jun	6	37859	...	GB 730606B	...	...
34	1973	Jun	6	67629	...	GB 730606C	2, 6, 10	See Ref. 10.
35	1973	Jun	10	75582	...	GB 730610	1, 6	R.A. = 68, decl. = +13 or R.A. = 127, decl. = −64(3)
36	1973	Jul	21	32113	...	GB 730721	2, 6	R.A. = 47, decl. = +37 or R.A. = 192, decl. = +65(10)
37	1973	Jul	25	61673	...	GB 730725	2, 6	R.A. = 75, decl. = +30 or R.A. = 154, decl. = −52(5)
38	1973	Sep	18	18632	...	GB 730918	2	...
39	1973	Sep	26	57893	9	GB 730926	2, 6	...
40	1973	Dec	17	29348	...	GB 731217	2, 6	...
41	1973	Dec	23	2387	...	GB 731223	2, 6	...

TABLE 1—*Continued*

No.	Earth Crossing Time Year	Month	Day	Seconds	Uncertainty[a] (s)	Name	References	Localization
42	1974	Jan	21	65143	...	GB 740121	6	...
43	1974	Apr	2	66031	9	GB 740402	6	...
44	1974	Jul	23	47487	...	GB 740723	...	...
45	1974	Jul	24	11804	9	GB 740724	...	...
46	1974	Aug	23	52544	9	GB 740823	6	...
47	1974	Sep	29	67903	...	GB 740929	2	...
48	1974	Dec	14	36874	9	GB 741214	6	...
49	1975	Nov	2	43518	...	GB 751102	...	...
50	1975	Dec	2	86398	...	GB 751202	...	...
51	1976	Jan	28	26969	...	GBS 0708+12	11	R.A. = 107, decl. = +12 (See Ref. 11.)
52	1976	Mar	22	55528	...	GB 760322	12	R.A. = 184.352, decl. = −1.967, R = 64.75 (0.05) (See Ref. 12.)
53	1976	Apr	7	10464	...	GB 760407	12	R.A. = 1.561, decl. = +0.715, R = 89.181 (0.016) (See Ref. 12.)
54	1976	Apr	19	26771	...	GB 760419	12	R.A. = 12.777, decl. = +5.487, R = 34.453(0.015) (See Ref. 12.)
55	1976	Jun	12	68619	...	GB 760612	13	...
56	1976	Aug	16	58532	...	GB 760816	14	See Ref. 14.
57	1976	Sep	3	1453	...	GB 760903	...	...
58	1976	Nov	23	68873	...	GB 761123	...	...
59	1976	Dec	4	79853	9	GB 761204	...	...
60	1976	Dec	9	3858	...	GBS 1748−71	...	R.A. = 267, decl. = −71.5(5)
61	1976	Dec	20	63512	...	GBS 2248−40	...	R.A. = 342, decl. = −40(10)
62	1977	Jan	7	79531	...	GB 770107	...	...
63	1977	Jan	31	37762	...	GB 770131	...	...
64	1977	Mar	10	38394	...	GB 770310	12	R.A. = 29.160, decl. = +11.932, R = 61.38(0.08) (See Ref. 12.)
65	1977	Apr	10	48447	...	GB 770410	...	...
66	1977	May	1	76559	...	GB 770501	...	...
67	1977	Jul	8	46230	...	GB 770708	12	R.A. = 105.258, decl. = +22.676, R = 14.86(0.06) (See Ref. 12.)
68	1977	Oct	20	28496	...	GB 771020	15, 16	R.A. = 214, decl. = −14, R = 61(2)
69	1977	Oct	29	42084	...	GB 771029	15	R.A. = 51, decl. = +19, R = 78(2)
70	1977	Nov	10	61965	...	GB 771110	15, 16	R.A. = 244, decl. = −21, R = 86(2)
71	1978	May	8	72878	...	GB 780508	...	R.A. = 32, decl. = +13, R = 49(2)
72	1978	May	19	26509	...	GB 780519	...	R.A. = 47, decl. = +18, R = 22(2)
73	1978	May	21	78826	...	GB 780521	...	Intersection of R.A. = 50.7, decl. = +18.6, R = 41.4(0.1) and R.A. = 12.0, decl. = +11.9, R = 25.75(25.75)
74	1978	Sep	14	60130	5	GB 780914	...	R.A. = 62.2, decl. = 27.7, R = 38.1(.3)
75	1978	Sep	18	71374	...	GB 780918	...	R.A. = 229., decl. = +38.5(7.0) or R.A. = 255.75, decl. = +39.6(7.2)
76	1978	Sep	21	14159	...	GBS 0852+34	...	R.A. = 133, decl. = +34(2)
77	1978	Oct	6	39593	...	GB 781006A	17	...
78	1978	Oct	6	51899	...	GB 781006B	17	R.A. = 34.6, decl. = −5.2, R = 33.7(2.7)
79	1978	Oct	12	62029	35	GB 781012	17	...
80	1978	Oct	13	53676	36	GB 781013	...	...

TABLE 1—*Continued*

No.	Earth Crossing Time: Year	Month	Day	Seconds	Uncertainty[a] (s)	Name	References	Localization
81	1978	Oct	19	66407	...	GB 781019	...	R.A. = 180.8, decl. = −7.8(3.3) or R.A. = 228.3, decl. = +35.7(4.2)
82	1978	Oct	23	62619	52	GB 781023	...	...
83	1978	Oct	25	85982	...	GB 781025	17	...
84	1978	Oct	26	29034	56	GB 781026	17	...
85	1978	Nov	4	58667	...	GBS 2006−22	17, 18, 19	R.A. = 301.5, decl. = −21.6(0.5)
86	1978	Nov	15	76044	...	GBS 1400+52	17	R.A. = 210, decl. = +52(1.5)
87	1978	Nov	19	34021	...	GBS 0117−29	20, 21	R.A. = 19.13, decl. = −28.9(0.1)
88	1978	Nov	21	5736	...	GBS 1703+01	...	R.A. = 255.7, decl. = +0.9(0.3)
89	1978	Nov	24	14130	...	GBS 1201+22	17	R.A. = 180, decl. = +22(1)
90	1978	Dec	17	73375	5	GB 781217	...	...
91	1979	Jan	1	604	4	GB 790101	17	R.A. = 230.4, decl. = −15.9, R = 55.9(0.5)
92	1979	Jan	5	29017	...	GB 790105	...	R.A. = 134.0, decl. = +26.4, R = 86.0(3.0)
93	1979	Jan	7	20155	...	GB 790107	17	...
94	1979	Jan	13	27360	...	GBS 1630−76	17	R.A. = 247.5, decl. = −76.5(0.5)
95	1979	Feb	11	41967	5	GB 790211	17	...
96	1979	Mar	5	29252	268	GB 790305	...	R.A. = 6.6, decl. = +12.6, R = 33.5(1)
97	1979	Mar	5	57125	...	GBS 0526−66	17, 22, 23, 24	R.A. = 81.49, decl. = −66.12(0.02)
98	1979	Mar	7	80327	...	GBS 1400−47	17	R.A. = 209.8, decl. = −46.8(0.5)
99	1979	Mar	13	62636	...	GB 790313	...	R.A. = 94, decl. = −46 or R.A. = 221, decl. = +73(0.5)
100	1979	Mar	25	49488	...	GB 790325	17	R.A. = 333.9, decl. = −83.3(8.3) or R.A. = 272.2, decl. = +31.9(1.3)
101	1979	Mar	29	80512	...	GB 790329	17	R.A. = 153.9, decl. = +11.6, R = 34.5(1.0)
102	1979	Mar	31	76172	...	GBS 1925+05	17	R.A. = 291, decl. = +5(2)
103	1979	Apr	2	34981	616	GB 790402	17	...
104	1979	Apr	6	42447	...	GBS 2311−50	17, 19, 25	R.A. = 347.80, decl. = −49.93(0.02)
105	1979	Apr	12	79346	653	GB 790412	17	...
106	1979	Apr	18	27660	...	GBS 0552−07	17, 19	R.A. = 88, decl. = −7(0.5)
107	1979	Apr	19	57406	...	GB 790419	17	R.A. = 356.3, decl. = −3.2, R = 43(1.5)
108	1979	May	2	15707	694	GB 790502	17	...
109	1979	May	9	1635	392	GB 790509	...	R.A. = 235.8, decl. = −20.5, R = 59.9(0.1)
110	1979	May	14	64308	440	GB 790514	17	...
111	1979	Jun	13	50755	...	GBS 1412+79	17	R.A. = 213, decl. = +79(0.5)

[a]Where no uncertainty is given, a value of ±1 s may be assumed.

REFERENCES.—(1) Strong, Klebesadel, and Olson 1974; (2) Klebesadel and Strong 1976; (3) Kane and Anderson 1976; (4) Palumbo, Pizzichini, and Vespignani 1974; (5) Share 1976; (6) Cline and Desai 1976; (7) Trombka *et al.* 1974; (8) Wheaton *et al.* 1973; (9) Imhof *et al.* 1974; (10) Ogelman *et al.* 1975; (11) Cline *et al.* 1979*b*; (12) Cline *et al.* 1979*a*; (13) Laros *et al.* 1977; (14) Sommer and Muller 1978; (15) Kuznetsov *et al.* 1979; (16) Estulin *et al.* 1979; (17) Mazets *et al.* 1981; (18) Zenchenko *et al.* 1979; (19) Estulin *et al.* 1981; (20) Zenchenko *et al.* 1980; (21) Cline *et al.* 1981; (22) Vedrenne *et al.* 1980; (23) Evans *et al.* 1980; (24) Cline *et al.* 1982; (25) Laros *et al.* 1981.

distances are much greater than the typical spacecraft separations. Nevertheless, due to the wide variety of instruments used to observe the events, there exists a range in the time dispersion which may be associated with the Earth crossing. The events themselves have durations ranging from several tenths of seconds to tens of seconds; different instruments, having different energy thresholds (ranging from ~50 to ~300 keV) and detection criteria, will initiate the storage of high time resolution data into their memories upon observations of features in the time history which may differ by several seconds in some cases. The Earth crossing times given here represent the times at which some feature of the event, usually the first large peak in the time history, would theoretically pass through the Earth's center. Except as noted, a maximum uncertainty of ±1 s can be assigned to the Earth crossing times due to the localization method alone.

Where an event may be localized, two types of localization data may exist. A gamma-ray burst may be localized (1) to an annulus or part of an annulus defined by two concentric, small circles on the celestial sphere; this results from a two-satellite arrival time analysis and is indicated by a right ascension, a declination, a radius, and an uncertainty, all in degrees. Thus, R.A. = 191, decl. = +20, $R = 27(3.5)$ means that the localization region is an annulus centered at a right ascension of 191°, a declination of +20°, with radii of 23°5 and 30°5. Alternatively, an event may be localized (2) to one or two irregularly shaped error boxes. This is a result of a localization using three or more satellites, sometimes with Earth or satellite blocking used to exclude various regions of the sky; it is indicated by a right ascension, a declination, and an uncertainty, all in degrees. Thus R.A. = 142, decl. = +62 or R.A. = 210, decl. = −29(3) gives the centers of two possible localization regions and indicates that each has a radius of 3°. A localization by four or more widely separated spacecraft is redundant; that is, the solution to the equations which define it is overdetermined. In any case, where references are given, they should be consulted for further details concerning the localization. Finally, for some events, a true localization is not possible, but a region of the sky may be excluded by Earth or satellite shadowing; this is indicated simply by a reference to published data. All coordinates in this catalog are for the 1950.0 equinox.

Some events, while meeting the separate spacecraft criterion for confirmation, have not been localized. In the case of the early events, this is due to the fact that all of the satellites were Earth orbiters, and the resulting localization included too large a portion of the sky to be meaningful. In the case of the later events, where interplanetary spacecraft were involved, a localization could not be achieved either because (1) the confirmation came from a rate increase in the real time data of a spacecraft and not a triggered response, resulting in a very crude localization at best, or (2) the confirmation came from the catalog of Mazets *et al.* (1981), for which accurate timing and time history information could not be obtained.

IV. COMPARISON WITH OTHER CATALOGS

Twenty-two of the first 35 events in this catalog have appeared in Strong, Klebesadel, and Olson (1974). The information given here supercedes this older list, reflecting updated spacecraft positional or timing information. Mazets *et al.* (1981) give positional information for 25 of the events in the present catalog; locations are given here for 15 of these events. Of the 15, 5 positions are found to be inconsistent with those of Mazets *et al.* (1981): the positional information for events 85, 91, 98, 101, and 111 in this catalog differs from that in Mazets *et al.* by varying amounts, although the differences are of the order of the characteristic dimension of the Mazets *et al.* error box in each case. In one of the five cases (event 85), our localization is redundant; in the other four cases, our localization results from a two-spacecraft or three-spacecraft arrival time analysis, and systematic errors, if present, could not be detected. While there is no reason to suspect that such errors exist in the data, the possibility cannot be excluded. We note that, in some cases, where these inconsistencies exist, our data are consistent with the annulus of location derived by Mazets *et al.* from a two-spacecraft arrival time analysis using *Venera 11* and *12* but inconsistent with that part of the annulus isolated using the cosine law detector response. This suggests that systematic errors (e.g., due to backscattering in the spacecraft, detector gain shifts, or spacecraft attitude determination) may have caused the latter procedure to give an incorrect result. Such inconsistencies were noted previously by Hurley (1981) based on the Mazets *et al.* catalog in preprint form; some positions, however, were corrected before inclusion in Mazets *et al.*

V. BIBLIOGRAPHY

The reference list given below is not meant to be exhaustive. References are given to indicate the appearance of an event in a previous catalog or to indicate the existence of some type of localization information, or for both purposes. In particular, references have not been given to papers including only spectral or time history information.

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