THE INTERPLANETARY NETWORK SUPPLEMENT TO THE FERMI GBM CATALOG OF COSMIC GAMMA-RAY BURSTS

K. Hurley1, V. D. Pal’shin2, R. L. Aptekar3, S. V. Golenetskii2, D. D. Fredericks2, E. P. Mazets2,21, D. S. Svinkin2, M. S. Briggs3, V. Connaughton3, C. Meegan4, J. Goldsten5, W. Boynton6, C. Fellows6, K. Harshman6, I. G. Mitrofanov7, D. V. Golovin7, A. S. Kozyrev7, M. L. Litvak7, A. B. Sanin7, A. Rau8, A. von Kienlin8, X. Zhang8, K. Yamaoka9, Y. Fukazawa10, Y. Hanabata10, M. Ohno10, T. Takahashi11, M. Tashiro12, Y. Terada12, T. Murakami13, K. Makishima14,22, S. Barthelmy14, T. Cline15,23, N. Gehrels15, J. Cummings15,24, H. A. Krinn17,25, D. M. Smith18, E. Del Monte19, M. Feroﬁ19, and M. Marisaldi20

1 University of California, Berkeley, Space Sciences Laboratory, 7 Gauss Way, Berkeley, CA 94720-7450, USA; khurley@ssl.berkeley.edu
2 Ioffe Physical Technical Institute, St. Petersburg 194021, Russia
3 University of Alabama in Huntsville, NSSTC, 320 Sparkman Drive, Huntsville, AL 35805, USA
4 Universities Space Research Association, NSSTC, 320 Sparkman Drive, Huntsville, AL 35805, USA
5 Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723, USA
6 University of Arizona, Department of Planetary Sciences, Tucson, AZ 85721, USA
7 Space Research Institute, 84/32, Profsoyuznaya, Moscow 117997, Russia
8 Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, Postfach 1312, D-85748 Garching, Germany
9 Division of Particle and Astrophysical Science, Graduate School of Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan
10 Department of Physics, Hiroshima University, 1-3-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8526, Japan
11 Institute of Space and Astronautical Science (ISAS/JAXA), 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
12 Department of Physics, Saitama University, 255 Shimo-Okubo, Sakuraku, Saitama-ku, Saitama 338-8570, Japan
13 Department of Physics, Kanazawa University, Kadoma-cho, Kanazawa, Ishikawa 920-1192, Japan
14 Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
15 NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, USA
16 UMBC/CRESST/NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, USA
17 CRESST/NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, USA
18 Physics Department and Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, Santa Cruz, CA 95064, USA
19 INAF/IASF-Roma, via Fosso del Cavaliere 100, I-00133 Roma, Italy
20 INAF/IASF-Bologna, Via Gobetti 101, I-40129 Bologna, Italy
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ABSTRACT

We present Interplanetary Network (IPN) data for the gamma-ray bursts in the first Fermi Gamma-Ray Burst Monitor (GBM) catalog. Of the 491 bursts in that catalog, covering 2008 July 12 to 2010 July 11, 427 were observed by at least one other instrument in the nine-spacecraft IPN. Of the 427, the localizations of 149 could be improved by arrival time analysis (or “triangulation”). For any given burst observed by the GBM and one other distant spacecraft, triangulation gives an annulus of possible arrival directions whose half-width varies between 0.4° and 32°, depending on the intensity, time history, and arrival direction of the burst, as well as the distance between the spacecraft. We find that the IPN localizations intersect the GBM 3σ error circles in only 52% of the cases, if no systematic uncertainty is assumed and added in quadrature, the two localization samples agree about 87% of the time, as would be expected. If we then multiply the resulting error radii by a factor of three, the two samples agree in slightly over 98% of the cases, providing a good estimate of the GBM 3σ error radius. The IPN 3σ error boxes have areas between about 1 arcmin² and 110 deg², and are, on the average, a factor of 180 smaller than the corresponding GBM localizations. We identify two bursts in the IPN/GBM sample that did not appear in the GBM catalog. In one case, the GBM triggered on a terrestrial gamma flash, and in the other, its origin was given as “uncertain.” We also discuss the sensitivity and calibration of the IPN.

Key words: catalogs – gamma-ray burst: general – techniques: miscellaneous

Online-only material: color figure, figure set, machine-readable tables

1. INTRODUCTION

This paper presents the latest in a series of catalogs of gamma-ray burst (GRB) localizations obtained by arrival time analysis, or “triangulation” between the spacecraft in the third

21 Deceased.
22 Makishima Cosmic Radiation Laboratory, The Institute of Physical and Chemical Research (RIKEN), 2-1 Hirosawa, Wako, Saitama 351-0198, Japan.
23 Emeritus.
24 Joint Center for Astrophysics, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250.
25 Universities Space Research Association, 10211 Wincopin Circle, Suite 500, Columbia, MD 21044.

Interplanetary Network (IPN; Table 1). In the present paper, we present the localization data on 149 bursts which occurred during the period covered by the first, two-year Fermi Gamma-Ray Burst Monitor (GBM) GRB catalog (Paciesas et al. 2012; 2008 July 12 to 2010 July 11). As the composition of the IPN has changed over the years, we present a summary of the instrumentation and techniques in the following section. Section 3 contains the localization data, which are also available on the IPN Web site.26 In Section 4, we discuss the statistics of the localizations.

26 http://ssl.berkeley.edu/ipn3/index.html
The composition of the missions and experiments comprising the interplanetary network changes as old missions are terminated and new missions are introduced. During the period covered in the present catalog, the IPN consisted of Konus-Wind, at distances up to around 5 lt-s from Earth (Aptekar et al. 1995); Mars Odyssey, in orbit around Mars at up to 1250 lt-s from Earth (Hurley et al. 2006); the International Gamma-Ray Laboratory (INTEGRAL), in an eccentric Earth orbit at up to 0.5 lt-s from Earth (Rau et al. 2005); the Mercury Surface, Space Environment, Geochemistry, and Ranging mission (MESSENGER), launched in 2004 August, and in an eccentric orbit around Mercury beginning 2011 March 18, up to 690 lt-s from Earth (Gold et al. 2001); and the Ramaty High Energy Solar Spectroscopic Imager (RHESSI; Smith et al. 2002), Swift (Goldstein et al. 2012), Fermi (Meegan et al. 2009), Suzaku (Takahashi et al. 2007; Yamaoka et al. 2009), and AGILE (Marisaldi et al. 2008; Del Monte et al. 2008; Tavani et al. 2009), all in low Earth orbit.

The detectors in the IPN vary widely in shape, composition, time resolution, and energy range. Also, onboard timekeeping techniques and accuracies are not the same from mission to mission, and spacecraft ephemeris data are given only as predicts for some missions. Since the accuracy of the triangulation technique depends on all these parameters, end-to-end calibrations and sensitivity checks are a constant necessity. For the current IPN, we utilize the following method. For every burst for which the Swift X-Ray Telescope (XRT) detects an X-ray afterglow, we search for GRB detections in all the IPN experiments. If the burst was detected by (1) Odyssey and Konus or by Odyssey and a near-Earth mission, (2) MESSENGER and Konus or by MESSENGER and a near-Earth mission, or (3) Konus and a near-Earth mission, we derive an IPN annulus by triangulation. We then calculate the angle between the annulus center line and the XRT position $\theta_X$, taken from the GCN Circulars, and which we take to be a point source, because its positional uncertainty is much less than the annulus width $d\theta$ (Figure 2). $d\theta$ is calculated such that the distribution of annulus widths is approximately Gaussian, so the distribution of $\theta_X/d\theta$ should follow a normal distribution with mean zero and standard deviation 1, if systematic uncertainties are neglected. We have used this procedure so far for 78 MESSENGER/Konus or MESSENGER/near-Earth triangulations, 292 Konus/near-Earth triangulations, and 72 Odyssey/ Konus or Odyssey/near-Earth triangulations. We find that for the interplanetary spacecraft a systematic uncertainty equal to roughly 0.75 times the statistical one is required to make the

### Table 1

Recent IPN Catalogs of Gamma-Ray Bursts

| Years Covered | Number of GRBs | Description |
|---------------|----------------|-------------|
| 1990–1992     | 16             | Ulysses, Pioneer Venus Orbiter, WATCH, SIGMA, PHEBUS GRBs$^a$ |
| 1990–1994     | 56             | Granat-WATCH supplement$^b$ |
| 1991–1992     | 37             | Pioneer Venus Orbiter, Compton Gamma-Ray Observatory, Ulysses GRBs$^c$ |
| 1991–1994     | 218            | BATSE 3B supplement$^d$ |
| 1991–2000     | 211            | BATSE untriggered burst supplement$^e$ |
| 1992–1993     | 9              | Mars Observer GRBs$^f$ |
| 1994–1996     | 147            | BATSE 4Br supplement$^g$ |
| 1994–2012     | 271            | Konus short bursts$^h$ |
| 1996–2000     | 343            | BATSE 5B supplement$^i$ |
| 1996–2002     | 475            | BeppoSAX supplement$^j$ |
| 2000–2006     | 226            | HETE-2 supplement$^k$ |
| 2008–2010     | 146            | GBM supplement$^l$ |

**Notes.**

- $^a$ Hurley et al. (2000b); $^b$ Hurley et al. (2000c); $^c$ Laros et al. (1998); $^d$ Hurley et al. (1999a); $^e$ Hurley et al. (2005);
- $^f$ Laros et al. (1997); $^g$ Hurley et al. (1999b); $^h$ Pal’shin et al. (2013); $^i$ Hurley et al. (2011b); $^j$ Hurley et al. (2010);
- $^k$ Hurley et al. (2011a); $^l$ Present catalog.
distributions consistent with normal distributions. An example is shown in Figure 3. Systematic uncertainties arise from numerous sources. Some are certainly negligible in some cases, while others may be important. But in almost all cases, it is impossible to assign an accurate number to them. A partial list follows, in no particular order.

1. Variations in the clock accuracy from one spacecraft to another. Different spacecraft have different ways of calibrating their clocks and assigning times to the time bins of GRB time histories. We know, for example, that in some cases the GRB timing is subject to uncertainties, even though the spacecraft oscillator is quite accurate.

2. Predict timing. In many cases, the time assigned to a GRB is a predicted time, and it is never updated. In other cases, such as Odyssey and MESSENGER, the time is eventually updated using an accurate model for the clock drift; in this study, the updated times have been used for these spacecraft. In other cases, no final clock corrections are applied.

3. Different time resolutions. For any given spacecraft pair, the time resolutions can be vastly different, and sometimes one is not an exact multiple of the other. One time history is adjusted to match the time resolution of the other spacecraft in the light curve comparisons. This can be done in a variety of ways, but each is subject to uncertainties. Even in cases where one time resolution is in principle an exact multiple of another, the true values of the bin widths can be slightly different from their nominal values due to different on-board electronics.

4. Spacecraft ephemerides. Some ephemerides are predictions, while others are final. In these comparisons, the final ephemerides were used where possible, but they were not always available.

5. Different energy responses of the various detectors. In most cases, the GRB light curves are recorded in different energy ranges from one another. Even in those cases where we attempt to match the energy ranges of the detectors

(i.e., where the photons are energy-tagged), the detector responses within those ranges are different due to the very different detector designs.

It is often possible to derive very precise triangulation annuli for bursts detected by Konus and the GBM, even though the distance between the spacecraft is not large. The reasons are first, that the first 1.024 s of triggered Konus data are transmitted with 2 ms time resolution; this is the finest resolution of all the IPN detectors which bin their data. Second, GBM time- and energy-tagged data can be utilized to match Konus’ time bins and energy range, minimizing two possible sources of systematic uncertainties. Thus for short-duration or intense GRBs, or bursts with fine time structure, Konus/GBM annulus widths as small as several arcminutes can be obtained (Pal’shin et al. 2013). To verify Konus-GBM triangulations we have derived Konus-GBM triangulation annuli for 52 precisely localized bursts. The 3σ half-widths of these annuli range from 0°11 to 21°8 with a mean of 3°0 and a geometrical mean of 1°19. Figure 4 shows the distribution of the offsets (in sigma) of the precise positions. The mean offset is 0.09 and the standard deviation is 0.77. The minimum offset is –1.40 and the maximum is 1.69. To calibrate the IPN sensitivity, we use estimates of the peak fluxes, fluences, durations, and $E_{\text{peak}}$ of a large number of GBM bursts. These are measured in the 50–300 keV range, and are given in photons cm$^{-2}$ s$^{-1}$ (measured over a 1024 ms period), erg cm$^{-2}$ s, and keV, respectively. At the time this catalog was submitted in its final version, there were 1078 GBM bursts with peak flux, fluence, and duration entries, and 482 with $E_{\text{peak}}$ entries. To calculate the IPN sensitivity, we determined (1) whether any other IPN spacecraft also detected the burst, and (2) whether Konus, MESSENGER, or Odyssey detected the burst. Only the latter detections can lead to meaningful

\[ \text{http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/w3query.pl} \]
Figure 4. Accuracy of Konus-GBM triangulations. The histogram shows the relative offsets in sigma between the annuli center lines and the XRT counterparts for 52 bursts. The mean is 0.09 and the standard deviation is 0.77. The solid line is a Gaussian fit to the histogram.

Figure 5. The IPN efficiency as a function of GRB peak flux. The peak flux is measured over a 1024 ms time interval by the GBM in the 50–300 keV energy range. Two efficiencies are shown. The solid line is the probability that any IPN experiment (other than the GBM) will detect the burst. The dashed line is the probability that Konus, Odyssey, or MESSENGER will detect it. Only the latter detections lead to accurate triangulations.

Figure 6. The IPN efficiency as a function of GRB fluence. The fluence is measured by the GBM in the 50–300 keV energy range. Two efficiencies are shown. The solid line is the probability that any IPN experiment (other than the GBM) will detect the burst. The dashed line is the probability that Konus, Odyssey, or MESSENGER will detect it. Only the latter detections lead to accurate triangulations.

Figure 7. The IPN efficiency as a function of GRB $E_{\text{peak}}$. As measured by the GBM, this is from a Band function fit to a single spectrum over the time range of the peak flux of the burst. Two efficiencies are shown. The solid line is the probability that any IPN experiment (other than the GBM) will detect the burst. The dashed line is the probability that Konus, Odyssey, or MESSENGER will detect it. Only the latter detections lead to accurate triangulations. The first and last two bins are based on 12 or fewer events, and have poor statistics.

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Triangulations, because of their larger distances from Earth. From these numbers, we calculate the detection probabilities as functions of flux, fluence, duration, and $E_{\text{peak}}$. The results are shown in Figures 5–8. In each of the four graphs, the detection probabilities (or IPN efficiencies) represent an integral over the other three variables, as well as over duty cycles, and, for all the instruments except Konus, planet blocking. The probabilities of IPN detections are 50% or greater for peak fluxes in the range 1–3 photons cm$^{-2}$ s$^{-1}$ and for fluences in the range $1–3 \times 10^{-6}$ erg cm$^{-2}$. 
Table 2
IPN/GBM Gamma-Ray-Ray Bursts

| Date       | Universal Time  | GBM Identifier     | Observed by               |
|------------|-----------------|--------------------|---------------------------|
| 2008 Jul 14| 02:04:12        | GRB080714086       | Kon                       |
| 2008 Jul 14| 17:52:56        | GRB080714745       | AGI, INT, Kon, MES, RHE, Swi |
| 2008 Jul 15| 22:48:40        | GRB080715950       | AGI, Kon, MES             |
| 2008 Jul 17| 13:02:35        | GRB0807157543      | INT                       |
| 2008 Jul 19| 12:41:34        | GRB080719559       | AGI, INT, Kon             |
| 2008 Jul 23| 13:22:19        | GRB080723557       | AGI, INT, Kon, MES        |
| 2008 Jul 23| 21:56:23        | GRB080723913       | Suz                       |
| 2008 Jul 23| 23:37:42        | GRB080723985       | AGI, INT, Kon, MES, Suz   |
| 2008 Jul 24| 09:37:40        | GRB080724401       | INT, Kon, RHE, Suz, Swi3  |
| 2008 Jul 25| 10:26:14        | GRB080725435       | INT, Kon, MES, Swi2       |

Notes.

a Universal time is the trigger time of a near-Earth spacecraft.
b Two events were not listed as GRBs in the GBM catalog; we have confirmed however that they are valid cosmic events.
c AGI: Asto-rivelatore Gamma a Immagini LLeggero (AGILE); INT: International Gamma-Ray Laboratory; Kon: Konus-Wind; LAT: Fermi Large Area Telescope; MAXI: Monitor of All-sky X-ray Image; MES: Mercury Surface, Space Environment, Geochemistry, and Ranging mission; MO: Mars Odyssey; RHE: Ramaty High Energy Solar Spectroscopic Imager; RXTE: Rossi X-Ray Timing Explorer; Suz: Suzaku; Swi: Swift.
d Burst was outside the coded field of view of the BAT, and not localized by it.
e Burst was localized by Swift-BAT; IPN triangulation cannot improve on this localization.
f Burst was localized by SuperAGILE and INTEGRAL-ISGRI; IPN triangulation cannot improve on this localization.
g Burst was localized by INTEGRAL-IBIS; IPN triangulation cannot improve on this localization.
h Burst was localized by SuperAGILE; IPN triangulation cannot improve on this localization.

Figure 8. The IPN efficiency as a function of GRB duration. As measured by the GBM, this is T90 in the 50–300 keV energy range. Two efficiencies are shown. The solid line is the probability that any IPN experiment (other than the GBM) will detect the burst. The dashed line is the probability that Konus, Odyssey, or MESSENGER will detect it. Only the latter detections lead to accurate triangulations. The first and last two bins are based on eight or fewer events, and have poor statistics.

Every cosmic burst detected by the GBM was searched for in the IPN data; GBM localizations were used to calculate arrival time windows for Odyssey and MESSENGER, but the total crossing time windows defined by light-travel times were examined in all cases. The resulting detections are given in Table 2. (Note that this table supersedes the information in Table 2 of Paciesas et al. (2012), which is incomplete.) Konus and Suzaku can detect bursts in both triggered (2–64 ms time resolution) and an untriggered (1–3 s time resolution) modes; both modes are counted as detections in this table. Also, detections by several instruments which are not part of the IPN have been reported in the table, namely the Fermi LAT, Monitor of All-sky X-ray Image (MAXI), and Rossi X-Ray Timing Explorer (RXTE).

Two events in Table 2 were detected by the GBM, but did not appear in the GBM catalog. The origin of GRB 091013 was classified as “uncertain.” However, the cosmic nature of this event is confirmed by Konus. GRB 100501 was detected by numerous IPN spacecraft, including the GBM. However, in that case, the actual GBM trigger was caused by a terrestrial gamma flash.

Whenever Konus (in triggered, high time resolution mode), Odyssey, or MESSENGER detected the burst, we calculated one or more triangulation annuli. The annuli are given in Table 3, and figures may be found in Figure 9. In general, the annuli obtained by triangulations are small circles on the celestial sphere, so their curvature, even across a relatively small GBM error circle, may not be negligible, so that a simple, four-corner error box cannot always be defined accurately. For this reason, we do not cite the intersection points of the annuli with the error circles. A prescription for deriving these points, however, may be found in Hurley et al. (1999a).

When three widely separated experiments observe a burst, the result is two annuli which generally intersect to define two small error boxes. The proximity to the GBM error circle may be used to distinguish the correct one. When Konus, Odyssey, MESSENGER, and a near-Earth spacecraft (including INTEGRAL) detect a burst, the position is over-determined. In these cases, a goodness-of-fit can be derived for the localization, and an error ellipse can be generated (Hurley et al. 2000a).
### Table 3

**IPN Annuli**

| GRB     | UT     | α    | δ    | σstat | α1   | δ1   | R1   | δR1   | α2   | δ2   | R2   | δR2   | β1   | β2   | α   | δ   | R   | α   | δ   | R   |
|---------|--------|------|------|-------|------|------|------|-------|------|------|------|-------|------|------|-----|-----|-----|-----|-----|-----|
| 080715  | 22:48:40 | 214.70 | 9.90 | 18.97 | 148.5700 | 14.4501 | 60.4476 | .2762 | 273.7129 | −26.1484 | 71.1746 | .2884 | 15.6 | 35.6 | ... | ... | ... | ... | ... | ... |
| 080723  | 23:37:42 | 105.30 | 71.10 | 18.25 | 98.9192 | 24.7391 | 49.8618 | 1.5218 | 158.3648 | 10.1273 | 70.8100 | .0376 | 40.0 | 65.0 | ... | ... | ... | ... | ... | ... |
| 080724  | 09:37:40 | 358.30 | 32.90 | 18.63 | 99.4409 | 24.6844 | 84.6742 | .6209 | 97.4219 | 21.5770 | 84.9255 | 1.1054 | 35.0 | 85.0 | 122.9 | −28.4 | 66.4 | ... | ... | ... |
| 080730  | 12:29:15 | 245.40 | 4.60 | 19.07 | 284.9798 | −23.2105 | 60.0101 | 11.7374 | ... | ... | ... | 28.2 | 48.2 | ... | ... | ... | ... | ... | ... |
| 080730  | 18:51:38 | 246.60 | 28.70 | 19.07 | 165.8007 | 6.4610 | 78.9123 | .0519 | 285.2320 | −23.1364 | 67.9570 | .8020 | 49.3 | 69.3 | ... | ... | ... | ... | ... | ... |
| 080802  | 09:15:10 | 154.30 | 40.70 | 21.80 | 105.5186 | 19.2785 | 60.6310 | 1.3190 | 107.8602 | 22.3437 | 56.7793 | .2517 | 4.6 | 90.0 | ... | ... | ... | ... | ... | ... |
| 080803  | 18:31:20 | 300.10 | 82.80 | 25.24 | 169.8581 | 4.3476 | 84.4750 | .4333 | 110.2713 | 17.1546 | 71.7722 | 11.7110 | 20.0 | 90.0 | ... | ... | ... | ... | ... | ... |
| 080806  | 21:29:40 | 241.80 | 46.70 | 19.99 | 292.5906 | −20.8196 | 79.4133 | 3.2320 | 172.9066 | 2.7178 | 74.0460 | .2645 | 34.5 | 90.0 | ... | ... | ... | ... | ... | ... |
| 080807  | 23:50:32 | 101.70 | −16.00 | 19.62 | 113.3163 | 20.6681 | 32.4763 | .3303 | ... | ... | ... | −36.5 | −16.5 | ... | ... | ... | ... | ... | ... |
| 080816  | 12:04:18 | 156.20 | 42.60 | 18.97 | 181.6313 | −2.0874 | 56.3418 | .2924 | 181.2257 | −1.9328 | 56.0851 | .1783 | 50.0 | 80.0 | ... | ... | ... | ... | ... | ... |

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
Although we utilize this procedure whenever possible, we do not quote the localizations as error ellipses in this catalog, because, like the annuli, their curvature can render a simple parameterization inaccurate. A number of degenerate cases can occur in a three-spacecraft triangulation; they are discussed in Hurley et al. (2011b).

When Konus and an interplanetary or near-Earth spacecraft observe a burst, it is often possible to define a long, narrow error box from Konus' determination of the burst's ecliptic latitude. This is derived from a comparison of the count rates on the two Konus detectors, and its accuracy is generally of the order of ±10\°. A study of over 1800 Konus events indicates that the ecliptic latitude limits determined in this way can be considered to be an ~95% confidence band. Systematic uncertainties usually prevent a more accurate determination.

IPN annulus widths are often comparable to, or smaller than, Fermi LAT error circle radii, and can therefore reduce the areas of LAT localizations. An example is GRB 090323 (Ohno et al. 2009; Hurley et al. 2009), for which a Swift ToO observation led to the discovery of an XRT (Kennea et al. 2009), optical (Updike et al. 2009), and radio (Harrison et al. 2009) counterpart.

3. TABLE OF IPN LOCALIZATIONS

The 21 columns in Table 3 give (1) the date of the burst, in yymmdd format; this contains a link to a figure on the IPN Web site showing the annulus or error box and the GBM error circle, (2) the Universal Time of the burst at Earth, (3) the GBM right ascension of the center of the error circle (J2000), in degrees, (4) the GBM declination of the center of the error circle (J2000), in degrees, (5) the 1\σ statistical GBM error circle radius, in degrees, (6) the right ascension of the center of the first IPN annulus, epoch J2000, in the heliocentric frame, in degrees (7) the declination of the center of the first IPN annulus, epoch J2000, in the heliocentric frame, in degrees, (8) the angular radius of the first IPN annulus, in the heliocentric frame, in degrees, (9) the half-width of the first IPN annulus, in degrees; the 3\σ confidence annulus is given by $R_{IPN1} \pm \delta R_{IPN1}$, (10) the right ascension of the center of the second IPN annulus, epoch J2000, in the heliocentric frame, in degrees, (11) the declination of the center of the second IPN annulus, epoch J2000, in the heliocentric frame, in degrees, (12) the angular radius of the second IPN annulus, in the heliocentric frame, in degrees, (13) the half-width of the second IPN annulus, in degrees; the 3\σ confidence annulus is given by $R_{IPN2} \pm \delta R_{IPN2}$, (14) and (15) the Konus ecliptic latitude band, in degrees, (16)–(18) the right ascension, declination, and angular radius of the Earth or Mars, if the planet blocks part of the localization, in degrees, and (19)–(21) any other localization information, in right ascension, declination, and angular radius, in degrees.

The GBM data have been taken from the HEASARC online catalog,28 if the localization source was “Fermi, GBM.” For bursts with other localization sources, the “human-in-the-loop” localization was used (V. Connaughton 2012, private communication). GBM localizations are subject to change, and are given here for convenience only. The latest online catalog should be considered to be the most authoritative source of the up-to-date GBM data. The data in Table 3 are also available electronically.29

4. A FEW STATISTICS

There are 491 bursts in the GBM catalog (Paciesas et al. 2012). Of these, 427 (87%) were observed by at least one other IPN spacecraft. They are listed in Table 2, and the number of bursts observed by each IPN spacecraft is compiled in Table 4. Those events which were not observed by an IPN spacecraft had fluences between $4.5 \times 10^{-8}$ and $9.5 \times 10^{-6}$ erg cm$^{-2}$, peak fluxes between 0.33 and 8.8 photons cm$^{-2}$ s$^{-1}$, and durations between 0.13 and 218 s, as measured by the GBM (Goldstein et al. 2012; Paciesas et al. 2012). For 149 of them, it was possible to improve the localizations by triangulation. The minimum and maximum 3\σ IPN annulus half-widths were 7.40 \times 10^{-3} and 31.9, and the average was 1\°.8. The IPN error boxes have 3\σ areas between about 1 arcmin$^2$ and 110 deg$^2$. Each IPN localization was compared to its corresponding GBM error circle, as given in the online catalog.30 In that catalog, the GBM localizations have been approximated as circles, with 1\σ (statistical only) radii. Assuming that they are described by a two-dimensional normal distribution, we would expect 87% of

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28 http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/w3query.pl
29 http://ssl.berkeley.edu/ipn3/index.html
30 http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/w3query.pl
the 3σ IPN localizations to agree with them (i.e., to have some intersection with them). We find only 52% agreement.

If a GBM systematic uncertainty of 6° is assumed, and added in quadrature to the statistical uncertainty, we find the expected 87% agreement. If that radius is then multiplied by three, the agreement becomes 98% (3 events with discrepant localizations), so that this can be taken as an approximation to a 3σ GBM confidence region for this particular GRB sample. A more detailed analysis of systematics is given in V. Connaughton et al. (2013, in preparation). Comparing each IPN area with its corresponding 3σ GBM area, as approximated above, we find an average reduction in area of a factor of 180.

5. DISCUSSION AND CONCLUSION

The Fermi GBM has proven to be a worthy successor to BATSE. It detects about 245 GRBs yr\(^{-1}\) and distributes their coordinates almost instantaneously to a wide astronomical community. The nine-spacecraft IPN is a good complement to it, just as it was to BATSE. It detects a total of about 325 bursts yr\(^{-1}\) (18 yr\(^{-1}\) are short-duration, hard spectrum GRBs; see Pal’shin et al. 2013), has virtually no planet blocking or duty cycle restrictions when all the spacecraft are considered, and it is capable of good localization accuracy at the cost of longer delays. There are many ground-based experiments, both electromagnetic and non-electromagnetic, which can take advantage of the smaller IPN error boxes, and for which delays are not an issue. In this sense, the GBM and the IPN both expand the reach of Swift, by localizing bursts which Swift cannot. For example, a search for gravitational radiation is in progress which utilizes the IPN data on over 500 GRBs, the most extensive such search to date; another search has begun for neutrinos, using IceCube data and almost 1000 IPN events.

This catalog represents the first installment of the IPN supplements to the GBM burst catalogs. Work is proceeding on the localization of IPN bursts observed during the third and fourth years of GBM operation. Data on some of these events may be found at the IPN Web site.\(^{31}\)

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\(^{31}\) http://ssl.berkeley.edu/ipn3/interpla.html