Progress with the Real-Time GRB Coordinates Distribution Network (BACODINE)

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The RA,Dec coordinates of gamma-ray burst (GRB) sources observed with BATSE on GRO are automatically determined and distributed in real time to members of the global scientific community. These data are now being used by 27 operations to enable searches for associated transients in a variety of other wavelength or energy regimes to identify the burst source objects. The minimum total delay time from the onset of a GRB to the receipt of its coordinates by distant experimenters can be under 4 sec, less than the duration of a typical GRB, and the maximum total delay is 7 sec, or longer, depending on the distribution method. Recent improvements to the BACODINE system and some future improvements are discussed. A summary of the follow-up observations made by the BACODINE sites are given.

INTRODUCTION

Past attempts to observe the counterpart of a GRB in other than the gamma-ray energy band have used (a) a "stare" mode operation looking for the counterpart during the "flaring" stage of the burst, or (b) a "directed observation" mode at the GRB error box long after the burst is over (during the burst's "quiescent" phase). The former method has suffered from poor sensitivities resulting from the large FOVs required to have a reasonable chance of catching a GRB. And the latter method, while having much more sensitivity, still has not been able to detect a quiescent counterpart. The BACODINE system allows intermediate-FOV instruments to make observations for the counterpart while the GRB is still bursting (3) (4). It does this by monitoring the real-time telemetry data from the BATSE, searching for GRBs, calculating the direction for the GRB, and distributing that RA,Dec direction information to follow-up observation sites around the world in a matter

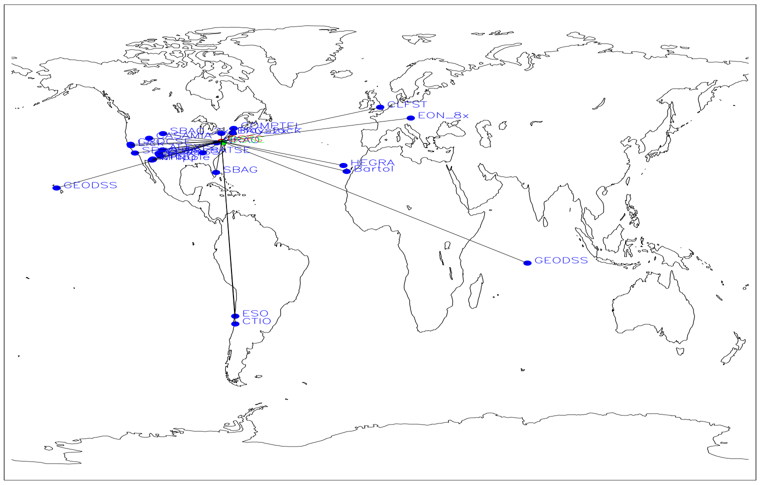

FIG. 1. World map of BACODINE sites.

of seconds.

The BACODINE system has been operating since January 1994 when it started with just the LLNL GROCSE instrument making follow-up observations (2). Since then, the number of operations using BACODINE has increased steadily to 27. They are shown in Figure 1.

The first 5 of the 6 distribution methods listed in Table 1 are currently implemented. The two phone/modem connection methods are seldom used because of cost or time delays. The e-mail method works well for sites on the Internet that have slow instrument response times. For fully-automated computer-controlled instruments with net access, the socket connection method is best. It is both fast and requires extremely little human oversite. Sites can simply use software provided by us to implement their end of the socket connection. The socket connection method is extremely fast in distributing the GRB coordinates. During the last month of operations for 7 socket sites, the average roundtrip time (from BACODINE to the site and echoed back to BACODINE) based on 244,116 packets is 0.566 sec. And less than 0.5% of the packets took longer than 2.0 sec. The one-way travel time is assumed to be half these values. The alpha-numeric beeper method allows for notification to anyplace within pager coverage.

IMPROVEMENTS TO THE SYSTEM

In the previous year several improvements and capabilities have been added to the BACODINE system. The e-mail and alpha-numeric pager notification methods were added and are described in (4). The delivery times for these two methods are 10-30 seconds and 1-3 minutes, respectively, depending on the geographic location of the recipient and the time of day.

TABLE 1. BACODINE Distribution Methods.

Time Delay [sec]	Method	Comments
0.3	Dedicated Phone/Modem	Fast & Expensive
0.1 - 1.0	Internet Socket	7 Worldwide Sites
10 - 30	E-mail	20 Worldwide Sites
50 - 100	Dialed Phone Connection	Long Setup Time
60 - 180	Alpha Beeper	RA,Dec,Time,Intensity
60 - 240	FAX	(not yet implemented)

Even with the improved trigger detection algorithm (4) which recovers the previously lost slow-rise-time GRBs, 40% of the BATSE triggers are such that the BACODINE system can not obtain a useful direction solution. About one fourth of these have been reclaimed by using the "MAXBC" data set in the BATSE telemetry stream. The BATSE on-board software scans the 64-msec sampled LAD rates in two energy bands (25-50 and 50-300 keV) for 10 minutes after the initial trigger looking for the maximum values. The 16 rates (the so-called MAXBC rates – maximum burst channel rates) are transmitted at T+10min. For those triggers that occurred during a telemetry gap (about 15%) and those that had low intensity emission for the first 10 seconds after the trigger (about 5%), a location can still be calculated from these rates and distributed to the sites, albeit at a much longer time delay. However, even with this 10 minute delay, it is still useful since some sites have comparable response times.

The same hardware and software that captures and processes the BATSE instrument data also captures the GRO-COMPTEL data when there is a GRB in the COMPTEL FOV. A ring buffer, with 120 sec of pre-trigger data and 260 sec of post-trigger, captures and automatically ftp's the COMPTEL data to a COMPTEL computer at UNH. There, it is automatically analyzed and if the GRB was bright enough, a location is available $\sim$15 minutes after the GRB. These COMPTEL locations are distributed over the Rapid Response Network (5). These GRB localizations are particularly useful because the COMPTEL error boxes are smaller than the BACODINE boxes. Heads-up notifications are also made for GRBs in the GRO-EGRET/OSSE FOVs and the ALEXIS spacecraft FOV.

The BACODINE system also redistributes location information derived from the Interplanetary Network (IPN) (6). Since there are only two spacecraft (GRO and Ulysses) that get their data to the ground in a timely fashion in the network at this time, only annuli are available. But when combined with BACODINE locations, arc segments are calculated and distributed to all BACODINE sites. This process involves automatically sending BATSE light curve data to a computer at UCB SSL which automatically searches for a match in the Ulysses data, and then sends the IPN arc solution back to the BACODINE. There are still two steps in this process with humans in the loop and a step of waiting for the daily Ulysses data dumps, but even so the time delays involved are in the range of 8 to 24 hours (a typical good-case scenario).

FOLLOW-UP OBSERVATIONS

There are 27 groups collaborating with BACODINE at 35 sites around the world. Of the 27 groups, 9 have optical instruments, 8 are radio, 4 are in the TeV/PeV gamma-ray band, and 6 are other gamma-ray spacecraft instruments (e.g. GRO-COMPTEL/EGRET, Ulysses and ALEXIS). Of particular interest are the automated instruments which are fully computer-controlled and have rapid response/slewing times, and hence have the shortest delay times to make an observation (2 optical instruments: LLNL GROCSE at Livermore, CA; the MIT ETC at Kitt Peak, AZ; and 2 radio: CLFST at Cambridge, England; FLIRT at San Diego, CA). Table 2 is a summary of the follow-up observations made by each site. The number of GRBs observed, the range of time delays, the range of percentage coverage of the final error box, and the instrumental upper limit are listed. Items not known or not available are listed as "TBD". While detailed discussion is not possible, several entries in the table are noteworthy. The 12 GROCSE observations have very short delay times and the upper limits are better than previous observations at this time delay (7). The 12 EON narrow and 34 wide FOV observations are important for their large numbers. The two automated radio sites, CLFST and FLIRT, have fast response times ($\sim$0-30 sec) and operate at a low enough frequency (151 and 74 MHz) that they have the potential to measure the distance to GRB source by the dispersion delay technique (9). Many of these sites have contributions in these proceedings.

THE FUTURE

There are three contributions to the relatively large size of the BACODINE error circles compared to the error circles determined by the BATSE team (see Table 1 in (4)). The first is due to using only the first 1 or 2 seconds of the GRB light curve. The counting-statistics contribution will become less than the systematic contribution when BACODINE starts distributing GRB notices based on more than the initial part of the light curve. These "updated" notices will be issued approximately 20 seconds after the initial trigger. Many sites will still be able to make use of this type of notification. The expected reduction will be a few degrees; mostly for the "low intensity" BACODINE triggers.

The other two contributions are due to the non-cos(theta) and earth scattering distortions of the BATSE detector response function from the "ideal physics" response function (8). We are working on porting the BATSE team's software and algorithms for these two corrections.

BACODINE will also redistribute HETE GRB locations. The smaller error boxes from HETE will allow more traditional, small FOV instruments with,

TABLE 2. Summary of Follow-up Observations Before Oct 1995.

Who	Number GRBs	Delay Times	Coverage [%]	Upper Lim
GROCSE	22	0-128 sec	85-100	7-8.5 mag
EON Narrow	12	5-48 hr	25-100	5-9 mag
EON Wide	34	0-10 hr	100	0-3 mag
ETC	1	90 sec	>50	10 mag
GEODDS	6	TBD	>90	>15 mag
SBAG	3	1-2 hr	35-90	8-15 mag
KPNO	1	28 hr	>99	>18 mag
Lick	2	1-2 day	TBD	18 mag
VLA	3	1-9 day	75-100	5 mJy
VLBA	1	5 day	>70	40 Jy
Tenerife	1	17 hr	20	6-20 Jy
Langston	3	12-24 hr	10-70	2 Jy
CLFST	2	TBD hr	TBD	TBD Jy
FLIRT	~12	1-11min	TBD	TBD Jy
Haystack	7	TBD	TBD	TBD Jy
OSSE	1	3 hr	<50	TBD
Whipple	6	.1-3 hr	~0-100	TBD
HEGRA	~12	TBD	TBD	TBD

therefore, better sensitivity to make follow-up observations. This combining of the HETE locations, plus the IPN notices, and the original BATSE BACODINE notices will make BACODINE an integrated network of GRB location information. Sites wishing to make follow-up observations need connect to only one source for GRB location information.

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