INTEGRAL BURST ALERT SERVICE

H. Pedersen, D. Jennings, S. Mereghetti
ISDC, Chemin d'Ecogia, CH-1290 Versoix, Switzerland
B. Teegarden
LHEA-GSFC, Greenbelt, MD, 20771, USA

ABSTRACT

Detection, precise positioning and spectral analysis of cosmic Gamma-Ray Bursts is one of the many objectives of the INTEGRAL mission. Due to their unpredictable nature GRBs can only be observed in serendipity mode. To allow and promote multiwavelength follow-up observations of such detections, it is desirable to make the information available to the community with minimum delay, hence via the Internet. Ideally, the data dissemination shall occur within a few seconds from the start of the GRB event so that follow-up observations can proceed while some of the sources are still emitting γ rays. The technical feasibility of building a system to disseminate INTEGRAL Burst Alerts in real time is currently under study at the ISDC. The findings of this study are presented here.

Keywords: Gamma-Ray Bursts; INTEGRAL.

1. INTRODUCTION

This paper reviews the state of knowledge regarding the technical feasibility of disseminating Gamma-Ray Burst (GRB) alerts in real time using the INTEGRAL spacecraft and associated ground-based systems. The justification for providing such an alert system is explored, and the possible strategies on how ISDC might construct a burst alert system are provided. Finally, quantitative estimates of the time delays resulting in the initial GRB acquisition to first INTEGRAL burst alert are presented.

2. Justification

The proposed INTEGRAL detection system builds upon NASA/GSFC's successful implementation of BACODINE, the Batse Coordinates Distribution Network (Barthelmy 1994). This was the first realization of a frequently expressed wish to have GRB positions made available to observers with considerable less delay than used to be possible.

Potentially, all of INTEGRAL's four instruments can participate in GRB detections. But because of their narrow fields-of-view, we shall not elaborate here on the possible role of OMC and Jem-X in a real time burst alert system. It is recognized, however, that data from both instruments should be useful in the analysis of detected GRBs.

IBIS *in principle* has the ability to perform GRB localizations to within a few arcminutes, and it should be possible to distribute the results in real time. In contrast to other missions and GRB detection networks, this is a significant development (see table I). Although SPI has moderate angular resolution ($\sim 3^o$) it should also be possible to use SPI data to localize bursts to within several arcminutes (Skinner et al. 1996). This refers to the final burst processing – the accuracy of real time detection and localizations with SPI is under study.

Table I. Summary of GRB alert systems.

Network	Delay	Accuracy	Frequency
BACODINE	5 sec *	4 - 20^o	300 /year
COMPTEL	14 min **	1^o	5 /year
IPN	$\sim$ 1 day	10' x 7^o	50 /year

Notes:

* Barthelmy (1994 and personal communication).
** Kippen (1996 and personal communication).

When evaluating the usefulness of an INTEGRAL burst detection system, it is necessary to consider the number of GRBs that could be detected by INTEGRAL. Provisional estimates have been obtained by scaling BATSE detection parameters to INTEGRAL. Using fully and partially coded FOV, these estimates show that 13 SPI detections and 6 to 24 IBIS detections per year are possible.

We have carried out a more detailed estimate for the case of the IBIS instrument. To minimize the involved uncertainties, it is based on the same integration times used for the BATSE triggering (Meegan et al. 1996). The effective area and the predicted background as a function of energy (15-600 keV) for the ISGRI detector have been used, and the decrease in sensitivity in the partially coded field of view has been properly taken into account. We have assumed a GRB spectrum described by a double power law with photon index -0.7 and -2, respectively below and above 100 keV. This is consistent with the average values observed during the GRB peak (Pendleton et al. 1994). The influence of S/C dithering is considered a relatively minor effect and has been disregarded in the simulations. The results of these computations are summarized in Table II.

Table II. Expected GRB detection rate for IBIS.

Burst trigger integration time	Frequency
1 second	10-15 year^{-1}
0.256 second	9-11 year^{-1}
0.064 second	7-8 year^{-1}

Based on the above estimates, we speculate that a total of 10 to 20 GRB detections per year could be expected from the INTEGRAL observatory.

In addition to the number of GRBs that INTEGRAL will detect, it is also important to consider the number of detected GRBs that can be followed up by ground-based observations. Observational constraint factors provided by Barthelmy (Barthelmy 1996) for clients of BACODINE show that as few as 1 in 160 GRBs (0.006 per day) can on average be observed in follow-up mode by a given ground-based optical observatory, and 1 in 80 (0.012 per day) GRBs for a given radio observatory. When BATSE-specific constraints are relaxed, these ratios improve to 1 in 60 (worse case) to 1 in 8 (best case) for optical observatories, and 1 in 20 (worse case) to 1 in 4 (best case) for radio observatories.

Using the above "relaxed" ratios as a rough guideline, it implies that there could be between 2 to 12 optical and 3 to 25 radio follow-up observations that a given ground-based observatory could conduct during the (5 year) lifetime of the mission. Therefore, INTEGRAL should seek the cooperation of a number of geographically distributed observatories to obtain meaningful follow-up observational data of detected GRBs.

3. GRB Alert Strategies

Any strategy for detecting and disseminating GRB alerts with INTEGRAL must attempt to do four things as fast as possible: (1) detect the presence of a GRB in progress, (2) validate the event as a real GRB, (3) accurately localize the position of the GRB and (4) send messages to subscribing external clients. Since ISDC will receive continuous instrument science and housekeeping telemetry packets directly from the Mission Operations Centre (MOC) at ESOC (Darmstadt, Germany) in real time, an automated data reception system will be in place to receive and format the incoming telemetry. Therefore, it should be possible to "piggyback" the ground-based GRB detection system upon the ISDC data reception subsystem.

3.1. GRB Detection

Of SPI and IBIS, only IBIS plans on implementing an on board burst detection mechanism. Assuming that the IBIS detection trigger is incorporated into the down-linked telemetry stream, the ground-based system should be able to find it by continuously monitoring the incoming telemetry. The presence of the burst trigger could be used to initiate other automated processes, such as burst localization and validation.

It should also be possible to examine the down-linked telemetry science packets containing event data and look for a statistically significant count excess. A GRB should be one of the few events that produces a large count excess with respect to the background on relatively short time scales. The ground-based system could take advantage of this fact to do fairly simple on the fly packet analysis. This technique will allow the use of SPI data for GRB detections.

3.2. GRB Validation and Localization

Once the presence of a GRB *candidate* is detected in the telemetry stream, it must be automatically validated as a true source and localized within the detector FOV. Experience with SIGMA (Sunyaev et al. 1993) shows that many GRB triggers can turn out not to be associated with a real source; furthermore, GRB localization is necessary to make full use of the detector's image resolving capabilities.

It should be possible to perform simple, quick validations and localizations of the GRBs using the event telemetry data from SPI and/or IBIS. The technique involves identifying a set of events received during a given integration period when the count rate was a preset number of standard deviations above the expected background. Then, the positional information associated with these events is used to deconvolve the detector image with the detector mask. The deconvolution process in this case can be fairly quick, theoretically taking less than a second to complete. The presence of a point-like source after the convolution "validates", or strongly implies, that the count excess was due to a GRB. The position of the source within the deconvolved image, along with S/C attitude information, provides the GRB location.

As an example, we have simulated a GRB detected with the IBIS-ISGRI detector layer. The detector image (see figure 1) containing $\sim$250 GRB counts and $\sim$600 background counts (i.e. a 10σ excess for a triggering time of 1 s) gives, after cross correlation with the decoding array, the sky image shown in figure 2. The GRB in the totally coded field of view is clearly visible and detectable by an automatic procedure.

To down-link the positional information for these $\sim$850 events will require $\approx$ 12 Kbits of telemetry. It is not unreasonable to expect that this information could be sent to ground in one second or less, since it will use only a 20% allocation of the 67 Kbits/sec telemetry stream for that second. Note that only the position of the events on the detector plane are necessary, energy and timing information can be downlinked at a later time.

Studies similar to the above for IBIS are also being carried out for SPI (G. Skinner, personal communication).

3.3. Spacecraft Attitude

In order to localize the position of a detected GRB, it will be necessary to know the attitude of the S/C as accurately as possible. ISDC will receive the predicted S/C attitude for pointings from the MOC two orbits before observation execution. Possible refinements to the predicted attitude will be delivered several hours before the beginning of an orbit. Additionally, the true S/C attitude for pointings (i.e., attitude reconstructions performed after a S/C slew) will be delivered every hour *a posteriori* during the mission.

The accuracy to which the true S/C attitude can be determined is related to the performance of the startrackers on board the S/C. The startrackers have a requirement to be accurate to within 1 arcminute, but experience from other S/C has shown startracker performance is usually better than this. Therefore, it is expected that reconstructed attitude determinations should have an accuracy of ≤ 1 arcminute, assuming that dynamic and static inaccuracies due to startracker–instrument misalignment are minor.

In many circumstances, it is anticipated that predicted and true S/C attitude for pointings should agree to within the required S/C pointing error of 5 ± 1 arcminutes. For most GRB detections, ISDC will almost certainly have to accept this uncertainty since it could be up to 80 minutes before the true position of the S/C is relayed from MOC to ISDC (5 minutes to perform the attitude determination, 15 to calculate new slew parameters and move the S/C, 60 minutes to relay the information). Additionally, there could be up to an 18 arcminute error in the S/C roll angle about the optic axis; this will result in an additional ≈ 1 arcminute error for points far from the instrument FOV center.

Attitude determinations for slews are not currently foreseen, although it might be possible to use XMM slew models to generate predicted attitude for INTEGRAL. If slew attitude is ultimately not provided then several options are still available to ISDC. These include using star tracker data to reconstruct S/C attitude, and interpolating S/C slew positions assuming slews occur along great circle arcs at constant velocity.

It might also be possible to use OMC data for an independent method of generating S/C attitude within (tens of) seconds from an S/C maneuver. OMC will routinely provide the (X,Y) offsets of a select set of objects in its FOV. These offsets could be used to produce attitude reconstructions for GRB localizations that are accurate to tens of arcseconds.

3.4. INTEGRAL Burst Alerts

Once the ground-based system has detected and/or localized a GRB it will transmit automated alerts to a set of subscribing clients. Hereafter, we shall refer to this process as an IBA (INTEGRAL Burst Alert). Besides GRBs, the notification system could theoretically be used to inform clients of the presence of other longer lived transient sources found by the ISDC quicklook analysis (e.g., TOOs).

The most efficient way to transmit IBAs will be via the Internet. TCP/IP socket connections between ISDC and subscribing clients offer the greatest speed, but require more effort to set up and maintain. Another option, Email, is flexible and simple to send/receive but can be two orders of magnitude slower than sockets. It should also be possible to make use of the existing BACODINE system for IBA dissemination. Initial contacts with the BACODINE group have been positive (S. Barthelmy, personal communication), and no substantial technical difficulties are foreseen.

4. Systematic Latency

Since the rationale for an INTEGRAL burst alert system is to facilitate immediate multiwavelength observations, it must be assured that the service functions with minimum delay. Estimates of the known systematic delays are summarized in table III.

Table III. Systematic latencies.

Process	IBIS	SPI
IBIS burst trigger time	0.05-1 sec	
Send on board trigger via broadcast packet	.1 sec	
Telemetry queue, - IBIS burst buffer - IBIS HK (burst flag) - SPI burst events	 1 sec 1-8 sec 	 1-600 sec
Light-flight time	.2-.4 sec	.2-.4 sec
DSN and MOC handling, transfer to ISDC	5-300 sec	5-300 sec
Detect burst flag in IBIS HK	.1 sec	
Detect burst in SPI event data		1-5 sec
Quick deconvolve data	.5 sec	1-5 sec
Validate source in data	.5 sec	.5 sec
Localize source and apply S/C attitude	.5 sec	.5 sec
Send IBA to clients using - TCP/IP socket - or Email	 .1-2.0 sec 5-30 sec	 .1-2.0 sec 5-30 sec

The delay estimates indicate that under optimum conditions, initial alerts from IBIS and SPI detections can reach clients between 8 to 15 seconds from the beginning of the event. What the realistic delay will be depends largely on the speed of data handling between the ground stations and MOC, and the total transfer time to ISDC. Although the MOC has a mission requirement only to deliver telemetry to ISDC within 5 minutes of ground station receipt (INT-MOC-PL-0100), ISDC has been informed that the true delivery time should be on the order of seconds.

Observations to date by BATSE show that as many as half of the GRBs last 8 seconds or longer, and a significant number last 30 seconds or longer; a non-trivial fraction even last longer than 100 seconds (see figure 3). Thus, a 8 to 15 second response time should be quite useful in implementing ground-based multi-wavelength follow-up observations. It even allows for the possibility of performing the follow-up observations while some GRBs are in progress.

5. Conclusions

The Integral Burst Alert service, to as far as we have been able to gauge the constraints, appears technically feasible and has the possibility of delivering precise Gamma-Ray Burst positions while some of these events are still in progress. Excellent opportunities for the detection of multiwavelength GRB counterparts should result, although it will be necessary to have a significant number of well distributed observatories as part of the network.

Due to attitude uncertainties, there are still some concerns about the accuracy to which a detected GRB can be localized in real time; the use of OMC data might provide a solution. Also, the potential telemetry transmission delays between the ground stations, MOC and ISDC could make real time detections difficult to achieve. In the coming years before launch we hope to further investigate these issues.

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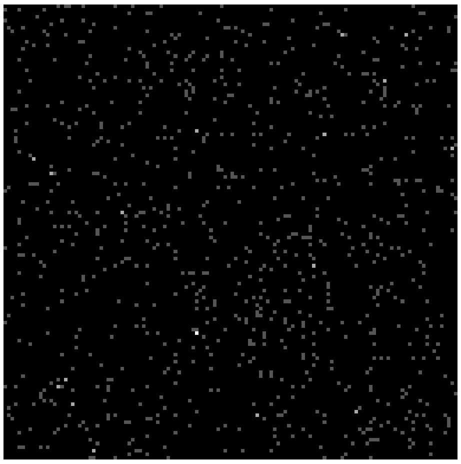

Figure 1: *View of the detector plane with 600 background and 250 source simulated counts.*

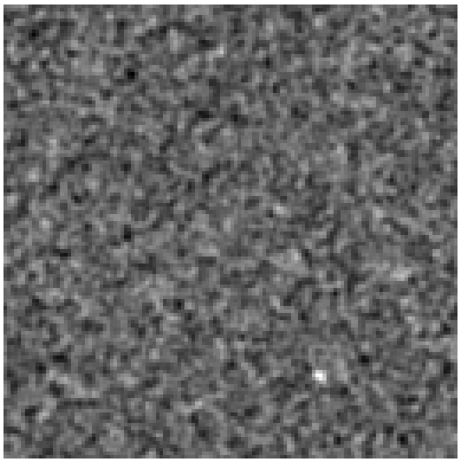

Figure 2: *The image resulting from deconvolving the detector mask and detector plane. The source is in the lower right of the image.*

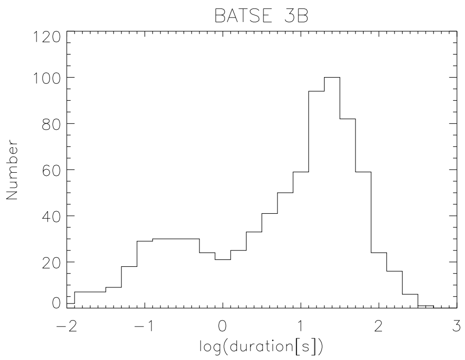

Figure 3: *GRB durations as derived from the 3rd BATSE Burst Catalog (http://cossc.gsfc.nasa.gov/cossc/batse)*