PROSPECTS FOR RAPID GAMMA-RAY BURST LOCALIZATION WITH INTEGRAL

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ABSTRACT The SPI and IBIS instruments on INTEGRAL will detect $\gtrsim$ 1 GRB/month within their large fields of view. The accuracy of localization with IBIS will be a few arcminutes, hence adequate for follow-up studies at large, ground-based telescopes. We report on the current studies and simulation activities aimed at designing at the ISDC an effective INTEGRAL Burst Alert System (IBAS) able to automatically distribute the positions of GRBs within a few tens of seconds from the event occurrence.

KEYWORDS: INTEGRAL, Gamma-ray bursts, software, burst detection.

1. INTRODUCTION

During the last two years, much progress has been achieved in the understanding of gamma-ray bursts (GRBs), in particular concerning their multiwavelength properties and typical distances. This was triggered by the BeppoSAX discovery of X–ray afterglows (Costa et al., 1997). Transient X–ray radiation following a GRB has now been detected in more than a dozen cases, often yielding to the identification of a possible radio and/or optical counterpart (e.g. van Paradijs et al. 1997).

The advance of information technology facilitates the world-wide data dissemination at large speed and low cost. Several minor telescopes have been constructed to react swiftly to such information (Boer et al., 1998; Williams et al., 1998; Castro-Tirado et al., 1998; Soldán et al., 1998).

Although INTEGRAL was not specifically designed to study GRBs, it has been recognized (even before the BeppoSAX results) that its good imaging properties allow the determination of arcmin-level localizations of GRBs and that the continuous telemetry link makes the discovery of these events possible in near real time (Pedersen et al. 1997). The predicted rate of at least one detectable GRB/month within the IBIS and/or SPI field of view has been corroborated by the BeppoSAX findings, which have also demonstrated the feasibility of such a project using coded mask imaging telescopes (Jager et al. 1997) conceptually similar to those on INTEGRAL.

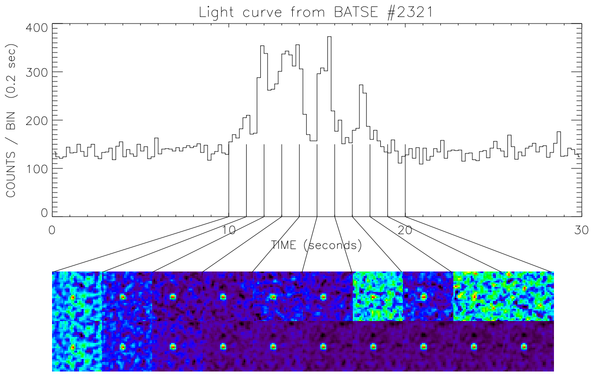

FIGURE 1. **Simulated GRB in the ISGRI fully coded field of view.** Photons arrival times are generated based on a light curve actually observed by BATSE. The peak flux is 0.85 ph cm^{-2} s^{-1} (50-300 keV) and a broken power law spectrum is assumed (α_{ph}=0.7 and 2, E$_{break}$=100 keV). The upper row diplays 15-300 keV images of 1 s integration each, while the images in the lower row are for increasingly longer time intervals (from 1 to 10 s). With a monitoring in 50 ms time bins and a threshold at 7σ, this GRB triggered at T=11.7 s. Less than 2 s later, the peak in the deconvolved image (third image in bottom row) has reached a S/N $\sim$20.

2. THE INTEGRAL BURST ALERT SYSTEM (IBAS)

Since no onboard GRB detection system is foreseen on INTEGRAL, the search for GRBs will be performed on ground by means of a near real time analysis done by the IBAS at the INTEGRAL Science Data Center (ISDC). This also implies that no special data acquisition modes are automatically entered following a burst. Therefore, the GRB detection and all the subsequent analysis (validation of the triggering events and localization) must be based on the data collected in the normal modes of operations of the instruments. The advantage of this scenario is the greater computing power available on ground that allows the implementation of more complex, sensitive and flexible algorithms. Furthermore, the triggering criteria can be more easily tuned to minimize false alarms and to optimize the detection of GRBs with different characteristics.

GRBs triggering shall result from the IBAS monitoring of ISGRI, SPI and JEM–X event data modes, e.g. by looking for significant excesses with respect to a running average, much like traditional on-board triggering. This will be done in parallel for different instruments, energy ranges and time bin durations. When a candidate event is detected, a process of image analysis shall start to verify the origin of the count rate variation. Images shall be accumulated for increasingly longer time intervals, deconvolved with very fast algorithms, and compared to the pre-burst reference images (see Fig. 1). Simulations have shown that in most cases it is possible to localize the GRB peak in the ISGRI deconvolved images within $\lesssim$ 1 s from the trigger time.

After a candidate GRB has been detected, other automatic processes shall validate the event before an external alert is sent. This validation uses the full information available, performing cross checks among the different instruments. The logic used to determine the validity of an event is still to be defined; it could require a certain percentage of the detection processes to trigger at once, and it has to assure that the event was not caused by an instrumental malfunctioning (e.g. a bad detector pixel). If the event is genuine then the satellite attitude information is applied to derive a sky position that is then automatically transmitted to all the subscribed users (by e-mail and/or direct TCP/IP socket). Additionally, secondary processes shall be started and their results analyzed offline by ISDC personnel. Because full event validation and localization might require a longer time, we foresee different levels of alert messages providing increasingly accurate and reliable information. For example, the errors on the GRB position can be reduced by analyzing images derived from the secondary offline processes.

3. IBAS PERFORMANCE

Under normal circumstances telemetry frames are expected at the ISDC within 30 s. In general, IBAS analysis might require between $\sim$2 and $\sim$20 s (the time for a GRB event triggering and validation is of course partially dependent upon the rise time of the event itself). Thus we foresee to be able to generate *first level* alerts within a few tens of seconds from the GRB occurrence.

The expected INTEGRAL attitude accuracy depends on three cases: (1) attitude during slews, (2) attitude at the start of a stable pointing period, and (3) attitude ten minutes after the start to the end of a stable pointing period.

For case (1) a slew path simulator generates predictions of the pointing direction every 10 seconds based upon the expected slew start and end times. In most circumstances these predictions should be accurate to within 10 arcmin (3 σ). With an average slew rate of 1 deg/min it should be possible to detect and localize short GRBs with reasonable accuracy even during slews.

For case (2) the attitude is based upon a prediction of the expected position with respect to the previously commanded slew. For slews shorter than 2 degrees these predicted values should have an accuracy of the order of the star-tracker/instrument alignment uncertainty (30 arcsec or less). For larger slews the predicted attitude accuracy is specified by ESA to have a 3σ absolute pointing error of no more that $5{\pm}1$ arcmin.

Approximately 5 minutes after the start of a pointing (case 3) a "snapshot" attitude reconstruction will be completed by MOC based upon the first downlinked star-tracker map. The result shall be made available to the IBAS within a maximum delay of 10 minutes since the start of the stable pointing (to be confirmed in operations), yielding, as above, an attitude with accuracy of $\lesssim$ 30 arcsec.

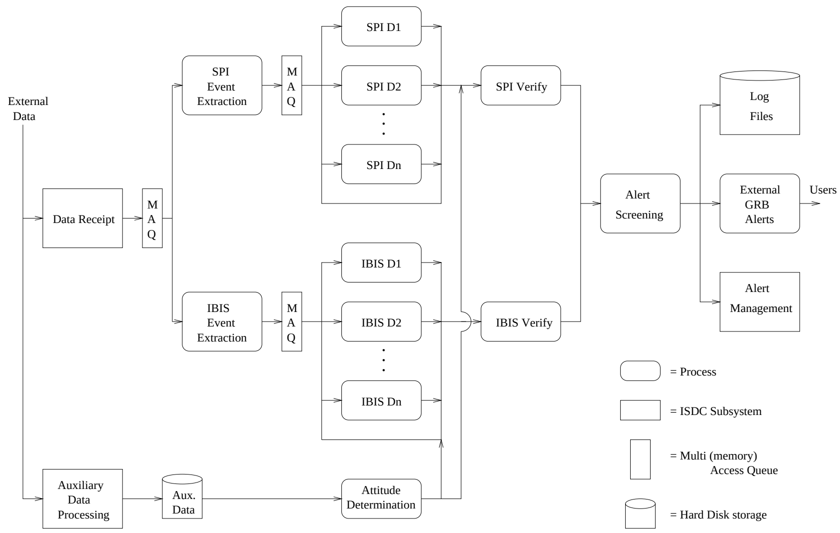

FIGURE 2. **Software Architecture of the IBAS.** Telemetry frames, received from the Data Receipt subsystem over a 128 kbs dedicated line, are quality checked, broken into data source packets and placed into a memory-resident Multi-Access Queue (MAQ). The MAQ is accessed via socket by several processes that select the relevant packets, extract the events, and place them into subsequent MAQs. When a GRB event is detected by one or more of the detection processes (Dn) for a given instrument, a message is forwarded to a verification process that determines whether the event is genuine. If the detected event is confirmed, the information is passed on to a final screening process that coordinates the detections from all instruments. A further validation logic is applied and secondary processes are spawned to perform a more detailed burst analysis. The screening process passes the GRB position and trigger time to the alert generation process, which broadcasts the information electronically to all subscribed clients. Currently two methods of alert transmission are foreseen: (1) Email and (2) direct TCP/IP socket. The former is useful for notifying individual researchers, the latter for triggering ground-based follow-up observations by automated telescopes.

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