The INTEGRAL Burst Alert System

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Abstract. ESA's INTEGRAL high-energy observatory is scheduled for launch in 2001. INTEGRAL carries two gamma-ray instruments, optimized respectively for spectroscopy and high-resolution imaging, complemented by an X-ray and an optical monitor. The high sensitivity of the INTEGRAL instruments will allow the detection and detailed studies of relatively faint bursts.

The INTEGRAL Burst Alert System (IBAS) is implemented as a ground based system, working on the near-real time telemetry stream. It is expected that the system will detect more than one GRBs per month in the field of view of the main instruments. Positions with an accuracy of a few arcminutes will be distributed to the community for follow-up observations within a few tens of seconds of the event. Furthermore, the system will upload commands to optimize the detection of an associated transient with the INTEGRAL optical monitor.

INTRODUCTION

INTEGRAL is a major gamma-ray astronomy mission of the European Space Agency currently under development, with a launch scheduled for the end of 2001 [1]. INTEGRAL is devoted to high resolution spectroscopy and high angular resolution imaging of the γ-ray sky, together with a broad coverage of the electromagnetic spectrum. These goals will be achieved by two main instruments (IBIS and SPI) optimized respectively for the angular and spectral resolution, complemented by two monitors in the X-ray (JEM-X) and optical (OMC) bands. The four instruments are co-aligned to simultaneously observe a large region of the sky. IBIS, SPI and JEM-X make use of the coded mask principle to obtain images at wavelengths where focussing techniques are unpracticable.

Thanks to its highly eccentric orbit with 72 hours period, INTEGRAL will spend most of the time outside the radiation belts and will almost continuously downlink the collected data. To optimize the imaging capabilities of the SPI instrument and to reduce background systematics effects, the pointing strategy will usually consists of raster scan observations, covering predefined patterns of directions around the main target. INTEGRAL will also devote a large fraction of its Core Program to scans of the Galactic Plane [2]. As a consequence, a non negligible fraction of the total observing time will consist of slews.

THE INTEGRAL INSTRUMENTS

IBIS [3] covers the energy range from 15 keV to 10 MeV thanks to two different position sensitive detection planes: a top layer composed of an array of 128$\times$128 CdTe pixels (2 mm thick) operating in the lower energy range, followed by a second layer made of CsI scintillators (64$\times$64 pixels, 3 cm thick) that extends the response to higher energies. A tungsten coded mask, placed $\sim$3.1 m from the detection plane, will provide an angular resolution of $12'$ over a wide field of view ($9^\circ \times 9^\circ$ full sensitivity, $19^\circ \times 19^\circ$ half sensitivity, $29^\circ \times 29^\circ$ zero response). The wide field of view and high angular resolution will make IBIS the most useful instrument for GRB studies. The data from its first layer (also known as ISGRI) will be in photon by photon mode, i.e. position, arrival time and energy information will be available for all the events. Due to telemetry limitations, the CsI layer (PICSIT) will normally work by integrating images (typically $\sim$1000 s long), and it is therefore less useful for the study of rapidly varying objects.

SPI [4] is optimized for detailed measurements of γ-ray lines and the mapping of diffuse sources with an angular resolution of $\sim 2^\circ$. The cooled Germanium detectors (19 pixels arranged in a hexagonal pattern) will allow precise measurements ($E/\Delta E \sim 500$ at 1 MeV) of the γ-ray energies over the 20 keV - 8 MeV range. Also SPI will always operate in photon by photon mode. Its field of view is similar to that of IBIS, and even if its angular resolution is worse, it can be used to confirm GRB detected with IBIS, and possibly to discover events that for some reason did not trigger in IBIS.

Another important characteristics of SPI is related to the possibility of using its anticoincidence shield (ACS) as a GRB detector. The SPI ACS consists of about 512 kg of BGO scintillators providing good sensitivity especially for GRB at large off-axis angles. The ACS will continuously produce a single light curve with the overall counting rate in time bins of 50 ms. Though no directional information will be available, the GRB detected in the ACS will allow the use of INTEGRAL as a near Earth spacecraft in the interplanetary network (IPN) for GRB location [5]. The expected rate of GRB detections in the ACS is $\sim$300 per year.

The JEM-X Monitor [6] will yield imaging with angular resolution of $3'$ in the 3 - 120 keV band over a $\sim 5^\circ$ fully coded field of view. It can be used to obtain a more precise localization of those GRB occurring in the central part of the IBIS/SPI field of view, that are bright enough in this energy range.

The OMC [7] will observe the optical emission from the prime targets of the other instruments. It consists of a 50 mm aperture telescope equipped with a passively cooled CCD. Its field of view is of $5^\circ \times 5^\circ$ and the pixel size is $\sim 17''$. During normal operations only a subset of windows in the OMC field of view will be transmitted to ground, corresponding to the position of preselected sources. Following the

IBAS detection of a possible GRB in the central region of the IBIS/SPI field of view, a telecommand requesting a new window to cover the GRB location will be automatically sent to the OMC. The expected limiting magnitude is a function of the galactic latitude. For high latitudes it is of the order of V=18-19 for a few hundred seconds exposure.

THE BURST ALERT SYSTEM

IBAS Overview

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 [8,9] at the INTEGRAL Science Data Center (ISDC) [10]. This gives the advantage of 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 monitoring of ISGRI, SPI and JEM–X event data, 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 and to assure that it was not caused by an instrumental malfunctioning or a background variation. Images shall be accumulated for different time intervals, deconvolved with very fast algorithms, and compared to the pre-burst reference images in order to detect the appearence of the GRB as a new source. Simulations have shown that in most cases it is possible to localize the GRB position in the ISGRI deconvolved images within less than one 1 s from the trigger time [8]. Of course this is dependent on the GRB light curve profile and on its intensity and location in the field of view. The image analysis will be based on the time intervals, derived from the GRB light curve, that optimize the signal to noise ratio.

After a candidate GRB has been detected, other automatic processes shall validate the event before an external alert is sent. 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). In addition, if the GRB is located in the sky region covered by the OMC, a telecommand will be sent to the satellite to reprogram the CCD windows in such a way to cover the GRB error box. 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.

Location Accuracy

The location accuracy of coded mask imaging systems depends on the signal to noise ratio of the source. For sources detected with a high statistical significance the accuracy can be a small fraction of the angular resolution. Theoretical evaluations, confirmed by several independent simulations, have shown that for ISGRI a source location accuracy smaller than $30''$ (90% confidence level) can be obtained for a signal to noise ratio of 30. In such cases, the final accuracy on the GRB location is also affected by the uncertainties on the satellite attitude (see below). For most of the detected GRB we expect however smaller signal to noise values, resulting in typical uncertainties, dominated by the photon statistics, of the order of $\sim$2-3$'$.

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 from about 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 5% of the slew path. The average slew rate during the Galactic Plane scans and during the normal dithering observations will be of the order of only $\sim 1^\circ$/min. Therefore, it will be possible to detect short GRBs even during slews, although their location accuracy will be worse.

For case (2) the attitude is based upon a prediction of the expected position with respect to the previously commanded slew. In most cases (i.e. slews shorter than 2°) these predicted values will have an accuracy of the order of the star-tracker/instrument alignment uncertainty ($30''$ or less). For larger slews the predicted attitude will have an error smaller than $5\pm1'$ (3σ).

Approximately 5 minutes after the start of a pointing (case 3) a "snapshot" attitude reconstruction will be completed based upon the first down-linked 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, yielding, as above, an attitude with accuracy of $\lesssim 30''$.

Time Performance

Under normal circumstances telemetry frames are expected at the ISDC within 30 s. In general, IBAS analysis might require between $\sim$1 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, in many cases, we foresee to be able to generate *first level* alerts while the GRB is still ongoing. Of course a trade off has to be made between accuracy of the results (i.e. confidence of a real GRB vs. false trigger, dimensions of the error region, etc...) and the rapidity of the alert. For this reason IBAS will automatically generate, for the same GRB event, several alert messages with increasingly more accurate results. These messages will be configured in such a way to allow an easy filtering by the users in order to react only to the situations that best fit their needs.

CONCLUSIONS

Although INTEGRAL was not specifically designed to study GRBs, its good imaging properties coupled with the almost continuous telemetry downlink, allow accurate localizations of GRBs in near real time [8]. Since no onboard GRB detection system will be available, the search for GRBs will be performed on ground by means of an automatic analysis performed at the INTEGRAL Science Data Center. We expect to detect and localize accurately $\gtrsim 1$ GRB per month [11], and to quickly disseminate its coordinates for rapid follow up observations at other wavelengths. Furthermore, the greater flexibility affordable with a ground based system, will allow the detection of GRB with different properties (e.g. slow rise time) that up to now failed to trigger GRB detectors.

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