Detection system response for burst-events on a spherical surface: comparison of three different monitoring algorithms using Monte Carlo modeling

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ABSTRACT

The development of a rotating detection system in space is proposed to assist in locating typical isotropicaly distributed burst-events. The system is based on several small angular openings (for example, 5 degrees opening each), bundled into a rotating detection system array, using a controlled stepper motor. A transmission device in the system will transmit the detected signals to an analyzing computer. In this work we simulated the response of rotating monitoring systems, using three different monitoring algorithms, in order to compare each system's efficiency according to its monitoring pattern. Burst-events counting on a spherical surface were simulated as a system, with a one or more detectors located on the center of a sphere. The burst-events monitoring was simulated in Monte Carlo calculations in three separate modules, describing several courses for the detectors' angular translations. The burst-events position was randomly changed at steps analogous to the monitoring period. The scored events resulting from each of the three algorithms were very similar, for 10^6 steps as well as for 10^7 steps. Enhancing the results statistics, by a factor of ten increase of the number of burst-events in the simulations, showed that the random monitoring algorithm is a three fold more efficient scoring compare to the other two patterned monitoring algorithms.

Keywords: Monte Carlo, modeling, GRB, gamma rays, rotating, detectors, random.

1. INTRODUCTION

During the late 1960's, the Vela satellites network discovered the cosmic γ-ray burst phenomenon[1], while monitoring the Earth surface, looking for evidence of clandestine nuclear tests. A complete Gamma Ray Bursts (GRB) mapping was not performed until the launch of the Compton Observatory in 1991[2]. The Compton Observatory (CGRO), the first mission to establish the gamma ray astronomy, covered gamma rays detection of several objects: the Sun, compact companion in stars binaries, supernova remnants, interstellar medium, galaxies, quasars, pulsars, supernovae and gamma ray burst sources[3]. The Compton Observatory was the largest satellite (17 ton) ever placed in orbit using a space shuttle.

The Gamma-Ray Bursts were detected by BASTE[4], one of the four instruments abroad CGRO, roughly once per day with a spatial accuracy of typically 5°, more than 2,000 bursts were detected since 1991 until 1996[5]. These bursts were found to be distributed isotropicaly on the galactic coordinates sphere surface, as shown in figure 1 (taken from Paciesas et al 1999).

GRBs and supernovae events are probable of short period gamma-ray sources. The BASTE GRB database showed that the GRB duration is distributed from 0.01 sec up to 8 min with higher probability in the shorter duration[6] (more than 50% of the events have a duration of 10 sec or less). The duration information and the typical angular resolution leads to a high probability to observe a single event in an order of $2\ 10^{-4}$ per angular-opening. The assumption is a 10 sec duration for a given event indicating that a typical event is taking place in a portion of 10^{-4} of the total observation time, and therefore adding an angular motion to the detection system may lead to an improved detection.

In 1996, another X-ray satellite, the Beppo-SAX, was operated with a couple of position-sensitive detectors acting as telescopes for low energy x-ray (0.1 – 10 keV) objects. Besides the two telescopes, a HPGSPC spectrometer was

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included, two wide field proportional counters, and a collimated Phoswich Detector System to monitor 60 – 600 keV gamma ray bursts with a temporal resolution of about 1 ms. The satellite was equipped with attitude orbital control system to ensure a 1' pointing accuracy of source observations, and a 10° per min slew rate maneuvers[7].

Detection systems suitable for randomly distributed gamma rays are very limited due to the restricted ability to support missions such as Beppo-SAX or Compton Observatory.

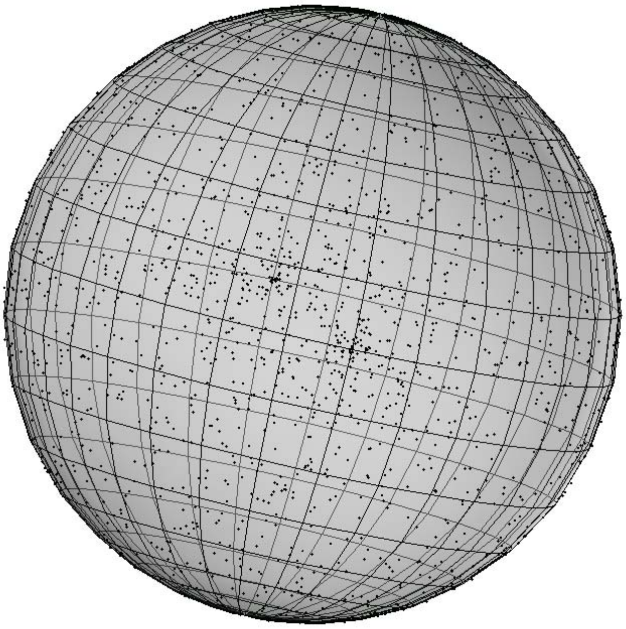

Figure 1: The GRB catalog of about 1600 objects, measured by BASTE, presented in a galactic coordinates system (data points taken from http://www.batse.msfc.nasa.gov/batse/grb/catalog/current/)

A new way of exploring the gamma ray sources is suggested, including simpler satellites that each contains one detection system, attached to servo motion motors, and a transmission device to transmit the measured output to an analyzing computer. The analyzing computer is proposed to be located on a communication satellite in order to collect and group the raw-data from all gamma burst events monitoring satellites, and to transmit the mapped signals to the mission station on Earth.

2. METHODOLOGY

In order to compare different sensing algorithm performances, general parameters were defined to simulate GRB emission, and detection system characteristics. Burst-events counting on a spherical surface were simulated as a system, including a detector, placed in the center of a sphere. A 5° opening-angle detector was described as a detecting point from the origin cone's vertex, for counting burst-events on a sphere. The detector responds only if an event occurs within a certain distance from the detecting cone, defined by the angle between two vectors, the center of the sphere to the burst-event point, and the detector's direction vector (Figure 2). The burst-events were defined as an array of b vectors; each vector containing longitude and latitude as components. Two random variables were generated in order to fill up the burst-events positions into the array. The detector was allowed to monitor only four times the whole sphere, using 10,000 steps, for a certain burst-events set. Assuming a 10 sec counting time at each step will result a period of 28 hours between each burst-events repositioning, similar to the natural occurrence timing of GRB.

Three different monitoring algorithms were simulated in order to compare each of the monitoring algorithms by computing their efficiency. The burst-events monitoring was computed using Monte Carlo calculations in three separate modules (computer codes written with FORTRAN 90), describing selected cases of detector angular translations. All the modules were written based on spherical coordinates with two vectoric-transformation subroutines from spherical to Cartesian presentation, and vice versa. A different subroutine was included in each module to calculate the angle between two vectors: the burst-event location, and the detection direction unit-vector. For every step, the subroutine calculated the angular distance in order to determine burst-events occurrence inside the 5° detector view range using equation 1.

$$\cos\alpha = \frac{\vec{a}\cdot\vec{b}}{\left|\vec{a}\right|\cdot\left|\vec{b}\right|} \tag{1}$$

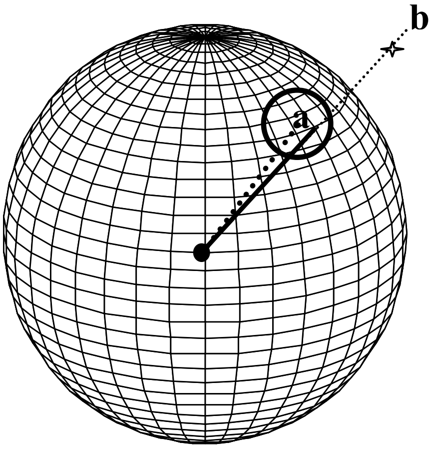

Figure 2: The 5° opening-angle detecting point from the origin cone's vertex vector (**a**), and the burst-event vector (**b**).

The monitoring algorithms description:

1. **RANDOM**: The detection vector was randomly changed after each step using two isotropic distributed random variables. The detection vector slew duration was defined as zero, for any step independent on the angular distance between the previous orientations to the next.

2. **SPHERE STRIPPING**: The detection vector was pointed to the upper latitude and the longitude was given a 5° change for every step. After a complete circle, the latitude was reduced by 5° and the next longitude was scanned until the whole sphere was scanned through a full monitoring period.

3. **QUADRANTIC STRIPPING**: For each hemisphere, four quadrants were defined in the step-by-step completion of the whole segment angular detection vector ranges. The steps were contributed correspondently to

each of the spherical quadrants. This method was set to present an equivalent of a bundled detectors array. This algorithm has an enhancing monitoring ability, since the detection vector is pointing four times on the Polar Regions, and twice on the Equator for each sequence. This method may be applied to galactic oriented objects, distributed along the galactic sphere Equator.

4. RESULTS

The three algorithms were tested with the same parameters in order to compare their results. In Fig. 3, isotropicaly distributed 200 computed burst-events are presented, with a single event (circled) detected by one of the algorithms. Since the probability to detect GRBs is low for a small opening detection system, variance reduction was performed by enhancing the burst-events population by a factor of ten. Table 1 summarizes the simulations results for each monitoring algorithm.

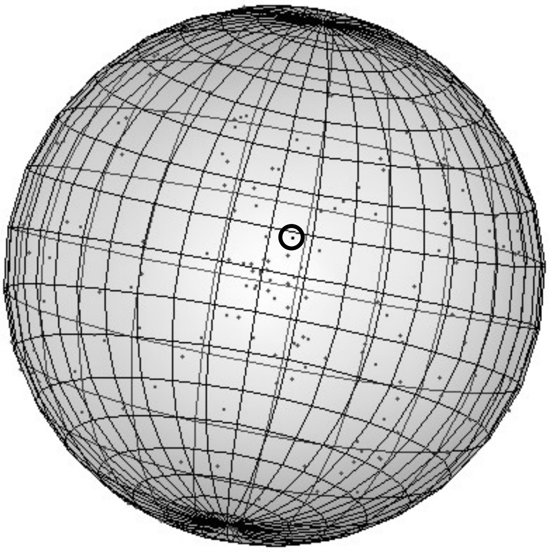

Figure 3: An example of a computed 200 burst-events set with one detected event, emphasized by a circle. It is shown that the burst-events were resulted in isotropic distribution.

The simulations results showed no apparent difference between the three algorithms for 200 bursts in 4 x 10 ^{3} periods (10 ^{6} steps). Enhancing the burst-events population revealed an advantage in the random monitoring compared to the other two algorithms that were found to provide a similar yield. Only the 4 x 10 ^{5} periods simulation lead us to the finding that the quadrantic stripping algorithm is the inferior monitoring method.

Table 1: The three monitoring algorithm results for different burst-events numbers, and with different period lengths. The total events results with their standard deviations are presented for each case.

Monitoring Algorithm	**200 Burst-Events**		**2000 Burst-Events**		
	4 x 10 ^{3} Periods	**4 x 10 ^{4} Periods**	**4 x 10 ^{3} Periods**	**4 x 10 ^{4} Periods**	**4 x 10 ^{5} Periods**
RANDOM	10 ± 3	133 ± 12	140 ± 12	1330 ± 36	13357 ± 116
SPHERE STRIPPING	9 ± 3	53 ± 7	40 ± 6	415 ± 20	4653 ± 68
QUADRANTIC STRIPPING	8 ± 3	37 ± 6	60 ± 8	388 ± 20	3636 ± 60

5. CONCLUSIONS

Since the GRBs spatial distribution is isotropic by nature, it was quite obvious to predict that a random monitoring algorithm should provide us with the highest yields. The comparison between the methods was done to compare the random monitoring algorithm exact ratio of yields to other patterned monitoring methods. The random monitoring was only three times more efficient than the two other monitoring algorithms. The sphere-stripping algorithm read about 25% more events compared to the quadrantic algorithm, and therefore the sphere-stripping method should be taken as the better of the two inspected patterned methods. Since only a small difference was resulted, the quadrantic-stripping method might be recommended for non-isotropic sources, such as galactic phenomena. In this work a single detection system was simulated, while the total efficiency of such methods has to be based on a large group of small detection satellites.

The Monte Carlo method was found as a very convenient tool, which can be applied to assist in monitoring assessments. The computing timing was recorded to be less than 14 hours for 10 ^{8} steps on a Pentium - 4 PC with 1.8 GHz Intel processor.

More monitoring algorithms are suggested to be examined in future simulations, due to different source properties, to compare their results for more assessments in the space-monitoring field.

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