Gamma Ray Burst Detection

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Abstract

This project is to find the optimal configurations in order to detect and locate a gamma ray burst upon its occurrence. We alter the angles between detectors, the thickness and material of casing, and the energy range of recorded detections to determine the best detection rates and localisation ability. The data samples themselves were obtained through computer simulation of gamma ray burst detections in space. Our results indicate that an angle of 45 degrees and a casing made of iron, with the detector looking at an energy band of 60 - 350 keV yields the greatest detection rate and accuracy in localisation.

Introduction

Gamma Ray Bursts (GRBs)

Gamma ray bursts are the most powerful explosions in the universe. Occurring across the universe, they remain visible even from distant galaxies, due to their highly energetic nature. As seen in figure 1, these explosions are followed by an "afterglow", a source of lower energy photons relative to gamma rays. After numerous efforts to provide an explanation regarding the nature of gamma ray bursts, many open questions remain. The most prominent theory as to the progenitor of short GRBs is a neutron star merger. This has received significant validation after a GRB detection following a gravitational wave on 17th August 2017.

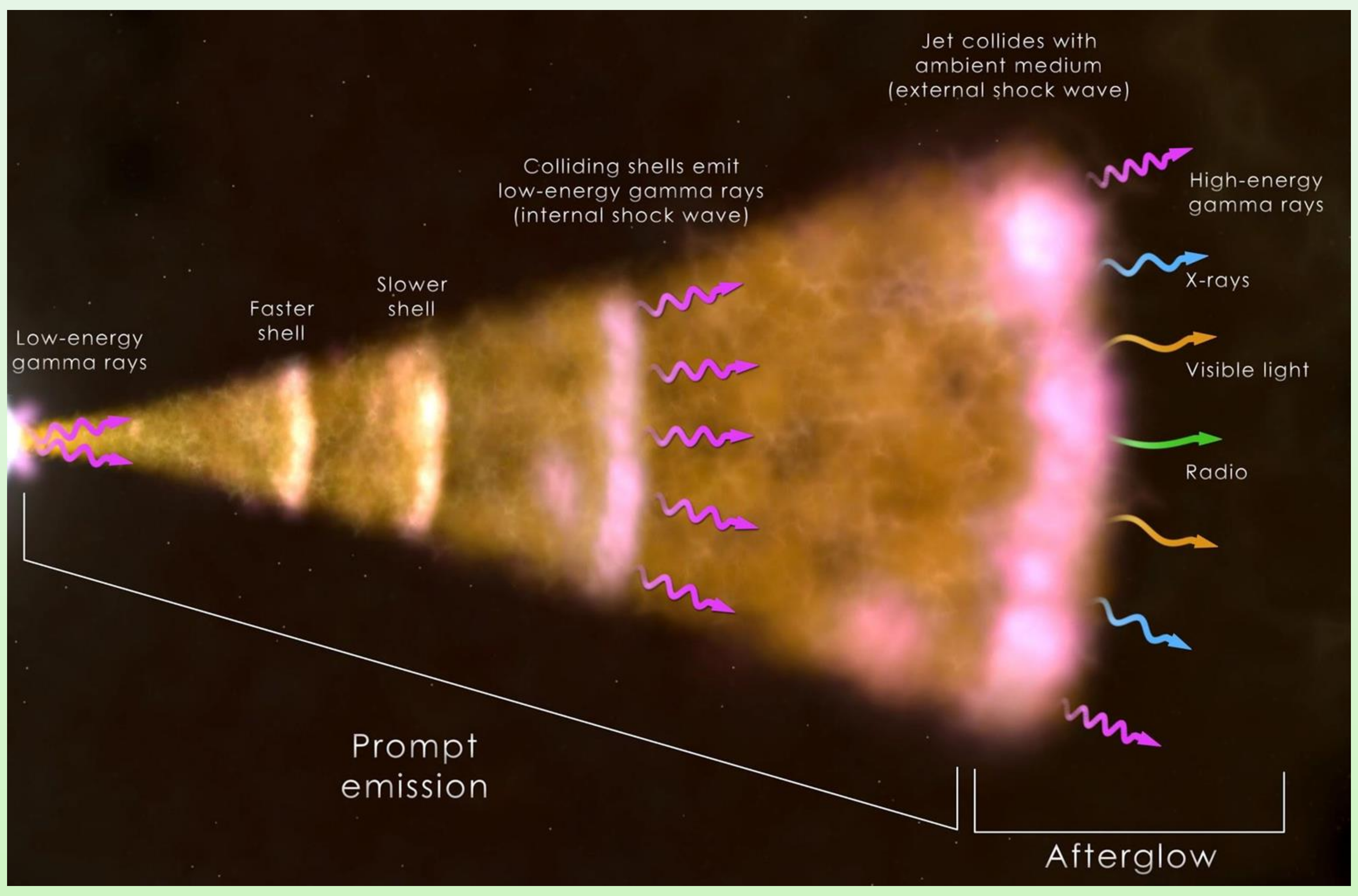

Figure 1: Gamma ray burst composition

Our Project

Our project has a focus on the detection and localisation of GRBs. It is planned to be sent to the International Space Station in NASA's collaboration mission with Technion: ISS-TAO; certain requirements and restrictions were given:

- Size; a probe that is too large will not attach to the mounting plate
- Weight; the plate it will be attached to has a maximum carry weight
- Reliability; once it's in space, we cannot make changes to it
- Heritage; ISS-TAO is a quick mission, so we need to include only technology with significant usage history in space.

The gamma ray burst detector will be accompanying a wide angle x-ray telescope (WFI) that is aimed at swift detection of the afterglow of the GRB, and other transients. The telescope will be capable of viewing a 19° by 19° area of the sky, and so our detector must be of equivalent accuracy or better. Since we do not know how long it takes the afterglow to appear, speed of detection and precise localisation are required, so that the WFI can view the afterglow, as close as possible to its initial appearance.

Our goal is to determine the optimal gamma ray detector configuration in relation to given restrictions and requirements, and only using up to five standard cylinder-shaped sodium iodide detectors due to heritage requirements.

Methods

Simulations

We simulate possible scenarios to find the ideal detector configuration using a simulation software called MEGAlib[1]. We would create a series of different layouts, and then implement them to get photon detection data. This data is then analysed to evaluate the effectiveness of each design.

We controlled the orientation and position of the detectors, then tested all of these configurations in an iterative manner, in order to find the optimal positions.

Data Processing

With these simulations, we could test the configurations in terms of detection and localisation ability.

To test detection ability we would translate configuration sensitivity to a value of estimated bursts detected per year. To test localisation ability, we would calculate the average area a configuration would guess the origin of a GRB with 90% certainty.

We also tested which data samples (energy band) would be most effective for analysis.

Results

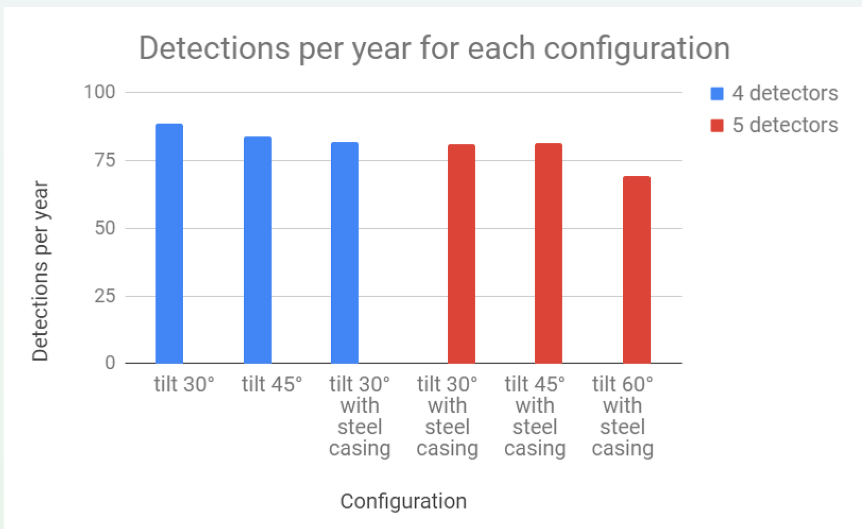

Figure 2: Estimated number of GRB detections per year for each tested configuration

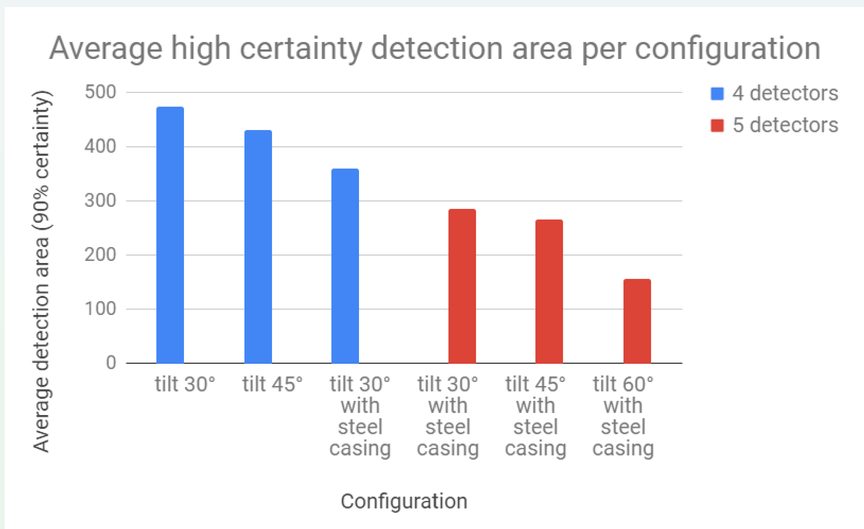

Figure 3: Average (high certainty) detection area for each tested configuration

Figures 2 and 3 show the final data on different configurations. All configurations contain either four or five detectors. Four detectors, placed facing 90 degrees from each other; those with five detectors have an additional vertical detector. The tilt attribute describes the angle at which the detectors are relative to vertical. Those labeled "with steel casing" are encased with 1.5 mm of steel rather than 2 mm of aluminium.

We're looking to maximise detections per year, and minimise the average detection area where there is a 90% certainty that the burst originated from it.

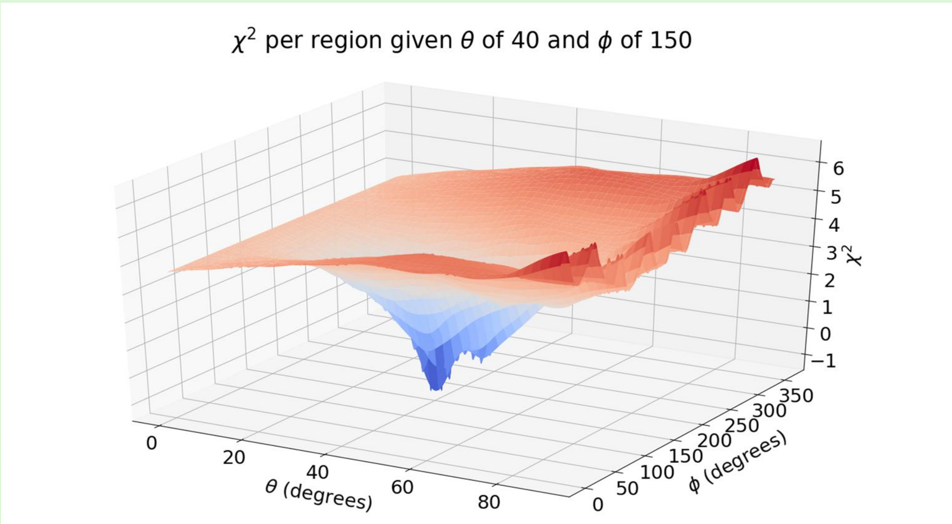

Figure 4: Chi squared value per region of sky for a GRB simulation originating from 40° by 150° with configuration tilt 45° with steel casing.

In figure 4, all values more than a specific distance from the minimum comprise an area where we could be certain from where the burst came, to a specific percent. In this graph, that area is the darker shades of blue. As you can see, the graph dips at around 40 by 150, where we simulated the burst to come from, indicating a successful localisation.

In addition to these results, we found an increase in detector sensitivity to gamma ray bursts when using the energy range 60 - 350 keV rather than the standard 50 - 300 keV, leading to a 14.2% increase in detections per year.

Conclusions

The data suggests that we have optimal balance between localisation and detection capabilities when the detectors are tilted 45° from vertical. Steel is more effective at blocking low energy photons than aluminium which translates to an increase in localisation accuracy, whilst the obstruction drops faster at higher energy for steel, so there is a minimal decrease in GRB detection. The increase in detection in the 60-350 keV range is due to the fact that this energy range starts from the point at which the gamma-ray photon background function[2] features a large reduction in background photons, until the point where the chosen Band[3] GRB function features a similar break, and so we'll find a large surplus of GRB photons over background photons.

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References

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2. Gruber et al. The Astrophysical Journal 520, 124, 1999
3. Band et al. The Astrophysical Journal 413, 281, 1993