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GAMCIT - A GAMMA-RAY BURST DETECTOR

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ABSTRACT

The origin of celestial gamma-ray bursts remains one of the great mysteries of modern astrophysics. The GAMCIT Get-Away-Special payload is designed to provide new and unique data in the search for the sources of gamma-ray bursts. GAMCIT consists of three gamma-ray detectors, an optical CCD camera, and an intelligent electronics system. This paper describes the major components of the system, including the electronic and structural designs.

SCIENTIFIC OBJECTIVES

Gamma-ray bursts were first reported in 1973 from observations on earth orbiting satellites. These energetic events are characterized by a rapid increase in the observed gamma-ray flux, at photon energies from tens of keV to greater than 1 MeV, followed by a decline which may be a simple exponential, or quite complex. In Figure 1 is shown three gamma-ray bursts observed by the BATSE detector on the Compton Gamma Ray Observatory [1].

It was quickly realized that these gamma-ray bursts represent one of the most energetic and violent phenomena observed in the universe. While many experiments have been developed to study gamma-ray bursts, including the BATSE experiment, their origin is still one of the great enigmas of modern astrophysics. The BATSE observations have yielded important data on the possible origin of these events. By observing the coarse location of the gamma-ray burst events, the BATSE researchers have determined that the sources of gamma-ray bursts are distributed isotropically. Further, from studies of the intensity of the bursts, they have deduced that the sources are not distributed homogeneously but have a definite boundary [2]. In Figure 2 is shown the distribution in Galactic coordinates of a sample of the gamma-ray bursts observed by the BATSE detector showing the isotropy of their locations. These facts indicate that the bursts are either local to the solar system, distributed in a large halo around the Galaxy, or at cosmological distances. Considerable theoretical effort is currently in progress in an attempt to explain the nature of these mysterious gamma-ray burst sources.

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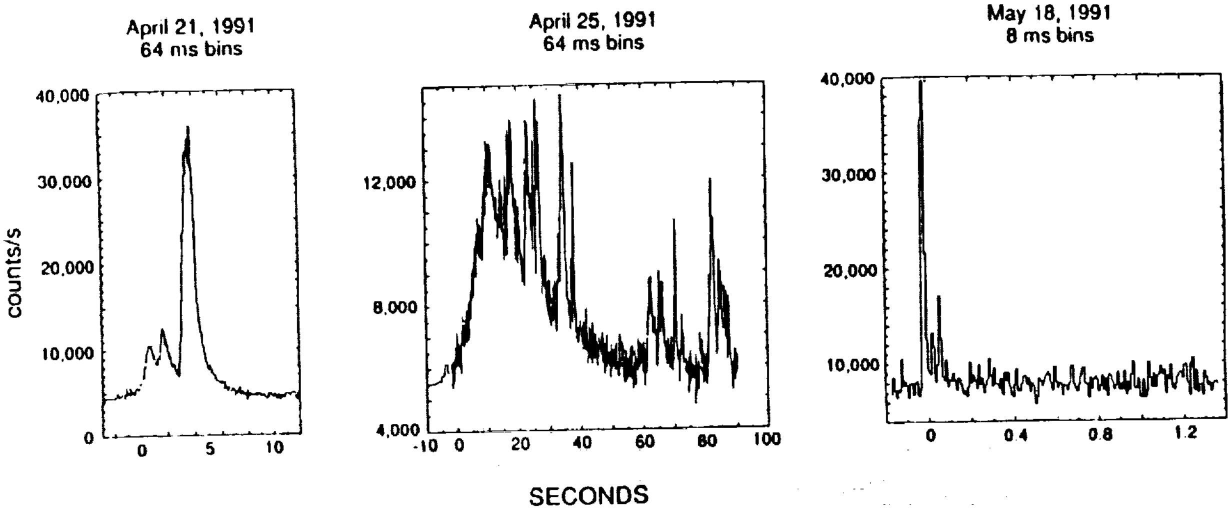

FIGURE 1. A sample of gamma-ray bursts as observed by the BATSE instrument on the Compton Gamma Ray Observatory (reproduced from [1]). These burst profiles show the wide variety of structure and varying time durations of gamma-ray bursts, from milliseconds to 100s of seconds. The energies of the gamma-rays in these plots range from 60 keV to 300 keV.

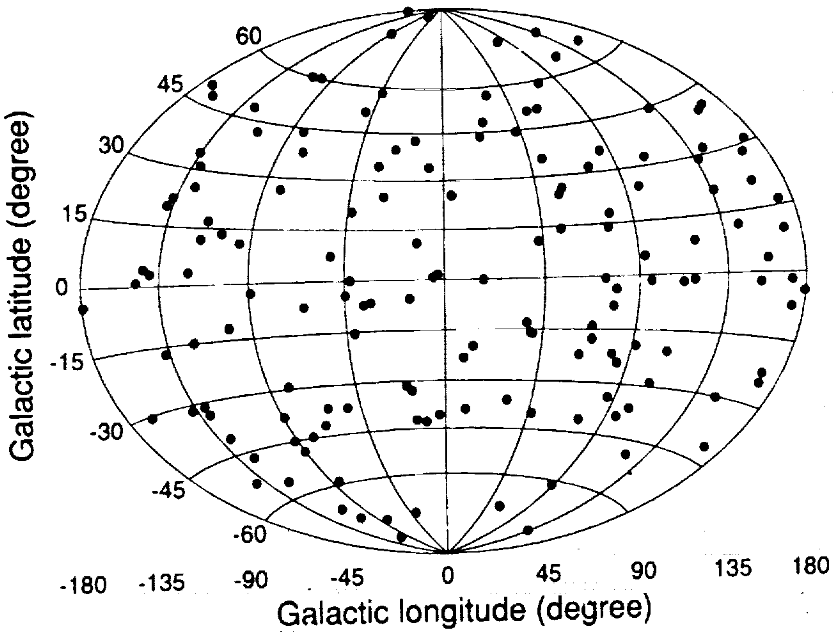

FIGURE 2. The angular location of gamma-ray bursts in Galactic coordinates as observed by the BATSE instrument on the Compton Gamma Ray Observatory (reproduced from [2]). The observed distribution shows no significant deviation from isotropy. In particular no enhancement along the Galactic plane (latitude=0) is seen, as would be expected if the sources of gamma-ray bursts had the same distribution as the stars in the Galaxy.

One theory suggests that neutron stars in binary systems are the culprit. In this scenario, a normal companion star transfers material into the extremely strong gravitational potential well near the neutron star. The energy this material gains is converted into gamma-rays near the surface of the neutron star producing a gamma-ray burst. Other models predict that comets, or other material is accreted by an isolated neutron star or black hole producing the gamma-ray burst. One interesting prediction of some of these theories is that as the gamma-rays hit the atmosphere of the companion star (or the material in orbit around the neutron star) some of the gamma-ray energy may be reprocessed into visible light. If these theories are correct, then a gamma-ray burst may be accompanied by a flash of optical light.

The scientific motivation for the California Institute of Technology Gamma-Ray Burst Detector (GAMCIT) project is to detect celestial gamma-ray bursts and to test the optical flash theory. Discovery of even a single optical flash, coincident with a gamma-ray burst, might well provide the key to crack the gamma-ray burst puzzle.

SYSTEM DESCRIPTION

Our technique is to use three conventional sodium iodide, NaI(Tl), scintillation gamma-ray detectors, combined with an image intensified CCD camera, sensitive to visible light. The GAMCIT payload provides, for the first time, truly simultaneous gamma-ray and optical observations. An intelligent electronics controller triggers the CCD camera when the gamma-ray burst is detected by the scintillation detectors. Three detectors are used to allow the requirement of a multiple coincidence between independent units, which reduces the chance of a background event mimicking a gamma-ray burst. It also provides some redundancy in the event of a hardware failure.

The time of occurrence of a burst is determined by using an on-board Global Positioning System (GPS) receiver, which provides a stable UTC clock and the position of the orbiter. This position and time are needed for correlation of the arrival time for a burst at the orbiter with the arrival time for the same burst at other satellites and spacecraft in the solar system. From these times triangulation can be performed to determine the direction from which the gamma-ray burst originated.

If we detect an optical flash, we should be able to localize the source to within a radius of less than 10 arcminutes. In addition, the CCD camera frames provide the aspect of the GAMCIT payload by determining the pointing direction of the experiment through the observations of bright star tracks.

To discriminate against solar flares, trapped electron precipitation events, and South Atlantic Anomaly crossings we also incorporate a small silicon charged particle detector. While solar flares resemble gamma-ray bursts, they are usually accompanied by a large charged particle flux, which will be registered by the silicon detector, allowing us to veto such events.

Based on input from the analog electronics and high speed logic system a microprocessor will control the CCD camera and GPS subsystem. All the data is processed by an intelligent microprocessor system and stored on high capacity hard disk drives for later analysis on the ground. A block diagram of the GAMCIT payload is shown in Figure 3.

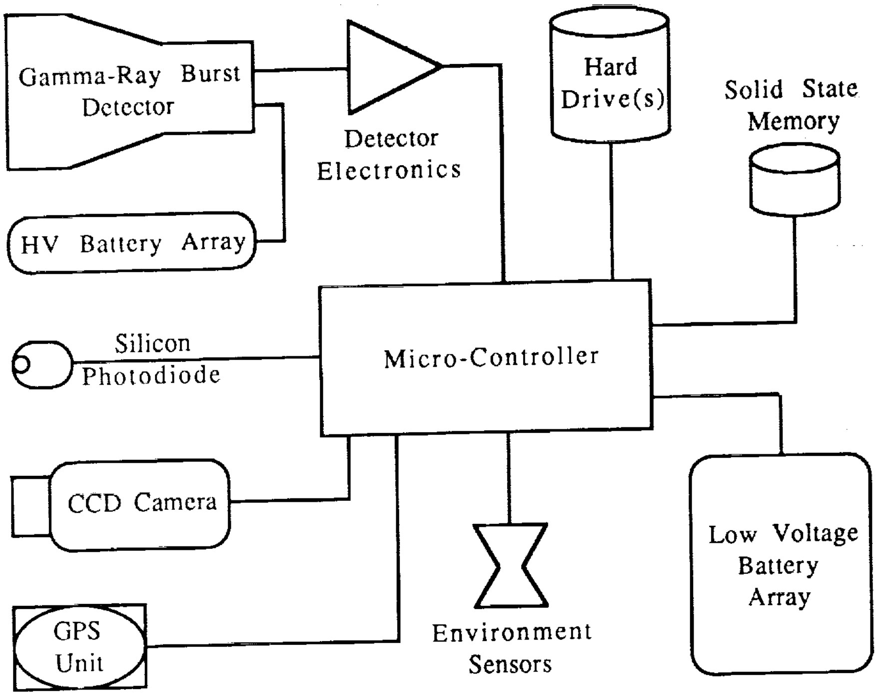

FIGURE 3. Block diagram of the Caltech GAMCIT payload.

ELECTRONICS

The challenge for the electronics design is to produce a sophisticated and intelligent data acquisition system while keeping the instrument within size, weight, and power constraints. The signal from the gamma-ray detector is conditioned by high speed analog circuitry and digitized for processing by a 16-bit CMOS, high-reliability, low-power microcontroller. This microcontroller serves the functions of instrument control, data handling, and system monitoring. The instrument utilizes hard disk drives designed for use in portable computers because of their high data density, low power consumption, and high mechanical reliability.

When the analog circuitry detects a gamma-ray burst it sends an interrupt to the microcontroller, which begins recording the burst and triggers the CCD camera to begin capturing optical information. The CCD data is compressed using image compression routines for efficient use of the mass storage resources. Additionally, the microcontroller monitors several analog sensors to aid in making operating decisions. These include the charged particle detector, a photodiode, which protects the CCD camera from the intense light of the sun, and an array of temperature sensors. These solid state sensors are used for temperature control and to aid in post-flight thermodynamic analysis of the system. A second microcontroller is used to control the GPS subsystem, which interfaces with the primary microcontroller. The GAMCIT mission may be one of the first occasions on which this precision system will be employed aboard the Space Shuttle.

Overriding all design concerns for the electrical systems is a need to stay within the power budget. As the GAS payload is independent of the Space Shuttle power system, it needs to provide its own supply of power. To conserve energy the microcontroller powers down instruments when they are not needed, such as the CCD camera and hard disk drive. The microcontroller stores the data in solid-state memory buffer until a sizable amount of information has been collected. The hard drive is then powered up and the data stored permanently. Similarly, the CCD camera can be powered up within a fraction of a second when a burst has been detected.

To meet the power requirements of the GAMCIT system, we chose to use gel cells for their space qualified status, relatively high current density, fairly flat discharge curve, and sturdy packaging, which protects the detector and the Shuttle from possible battery leaks.

In Table I we list the power estimates of the major components of the GAMCIT system.

TABLE I.- POWER BUDGET ESTIMATES

Component	Power Estimate	Comments
CCD camera	5 Watts	low duty cycle
GPS System	1.5 Watts	
Hard Disk Drive	2 Watts	low duty cycle
Photomultiplier Tubes	1 microWatt	separate high voltage system
Logic Circuits	0.5 Watts	microcontroller
Analog Circuits	0.5 Watts	amplifiers, sensors

MECHANICAL

The challenge for the structural design of GAMCIT is to provide a one atmosphere pressure environment for the electronic components while allowing an optical window to view the sky in the search for the possible optical counterparts to gamma-ray bursts. To satisfy both requirements, a Motorized Door Assembly (MDA) and specially designed pressure vessel are being used.

A custom aluminum/Kevlar top for the pressure vessel has been designed to accommodate the gamma-ray detectors, the optical window, the GPS antenna, and the MDA. Aluminum and Kevlar were chosen both to minimize the absorption of gamma-rays and to provide a strong structure for the pressure vessel.

The circular pressure vessel lid is divided into four quadrants, three of which are of a minimum thickness for the gamma-ray detectors. The fourth quadrant contains the GPS antenna and a 2.5 cm diameter quartz window through which the CCD camera has an approximately 110-degree view of the sky. The three NaI(Tl) crystal detectors, their corresponding photomultiplier tubes, the GPS antenna, and the CCD camera are all directly connected to the lid, as well as to the main support structure.

The main support structure consists of two aluminum cross-pieces which span the full length of the payload. The electronics box for the experiment is attached to the mid-section of the cross structure while the batteries are located at the bottom of the pressure vessel, in a separate sealed and vented container. The aluminum cross structure minimizes the response of the payload to the vibrations induced during the launch and landing phases of the orbiter since it is inherently strong and resistent to vibrational modes at low frequency. The only moving parts in the payload, other than the MDA, are the hard disk drives. These units were designed for use in notebook personal computers and in all cases meet or exceed the requirements for use on the Space Shuttle by a large margin. Additionally, a finite element analysis is being performed for the vibration stress induced.

The thermal design of GAMCIT results from the goal of keeping the gamma-ray detectors, the CCD camera, and the other interior components within their operating temperature ranges. A thermal system resulting from a finite element transient thermal analysis is being designed with insulating materials and heating elements in order to maintain the interior vessel temperature at 20°C±15°.

CONCLUSIONS

The GAMCIT experiment promises a guaranteed scientific return, as the gamma-ray burst observations will provide important data which can be combined with results from other detectors on ULYSSES, Pioneer Venus Orbiter and the Compton Gamma Ray Observatory. The observation of even a single optical flash would as well provide a stringent constraint on gamma-ray burst theories.

GAMCIT is the first payload being built by the Caltech Students for the Exploration and Development of Space. There are a total of fourteen undergraduate students presently working on GAMCIT, divided into four teams - electronics, structural, thermal, and safety. The real-life experience of designing and constructing space hardware isn't normally taught in a university curriculum. Thus, the Caltech GAMCIT program is providing a strong educational role in the training of future scientists and aerospace professionals.

REFERENCES

1. Fishman, G.J., Meegan, C.A., Wilson, R.B., Paciesas, W.S., Pendleton, G.N., The BATSE Experiment on the Compton Gamma Ray Observatory: Status and Some Early Results, NASA Conference Publication 3137, 1992, pp. 26-34.

2. Meegan, C.A., Fishman, G.J., Wilson, R.B., Pacieses, W.S., Pendleton, G.N., Horack, J.M., Brock, M.N., and Kouveliotou, C., Spatial Distribution of Gamma-ray Bursts Observed by BATSE, Nature, 1992, vol. 355, pp. 143-145.