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FINAL REPORT

to

The National Aeronautics and Space Administration

for

Development of A Broadband High-Energy Gamma-Ray Telescope using Silicon Strip Detectors

Grant Number: NAGW-3489-4

Performance Period (including no-cost extension): 04/01/93 - 04/30/97

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1. INTRODUCTION

The research effort support by NAGW-3489-4 has led to the development and demonstration of technology to enable the design and construction of a next-generation high-energy gamma-ray telescope that operates in the pair-production regime ($E > 10$ MeV). In particular, the technology approach developed is based on silicon-strip detector technology. A complete instrument concept based on this technology for the pair-conversion tracker and the use of CsI(Tl) crystals for the calorimeter is now the baseline instrument concept for the Gamma-ray Large Area Space Telescope (GLAST) mission. GLAST is NASA's proposed high-energy gamma-ray mission designed to operate in the energy range from 10 MeV to approximately 300 GeV. GLAST, with nearly 100 times the sensitivity of EGRET, operates through pair conversion of γ-rays and measurement of the direction and energy of the resulting e^+-e^- shower. The baseline design, developed with support from NASA under NAGW-3489-4, includes a charged particle anticoincidence shield, a tracker/converter made of thin sheets of high-Z material interspersed with Si strip detectors, a CsI calorimeter and a programmable data trigger and acquisition system. The telescope is assembled as an array of modules or towers (see Figure 1 below). Each tower contains elements of the tracker, calorimeter, and anticoincidence system. As originally proposed, the telescope design had 49 modules. In the more optimized design that emerged at the end of the grant period the individual modules are larger and the total number in the GLAST array is 25. Also the calorimeter design was advanced substantially to the point that it has a self-contained imaging capability, albeit much cruder than the tracker.

The research program under NAGW-3489-4 was carried out in close collaboration with the Stanford Linear Accelerator Center (SLAC), the Naval Research Laboratory, the University of California at Santa Cruz, and Goddard Space Flight Center. The principal responsibility of the Stanford group was for the overall coordination of the GLAST SR&T effort, the definition and initial development of the GLAST data acquisition and trigger system (DAQ) for the prototype GLAST module, collaboration with the Naval Research Laboratory (NRL) on the CsI calorimeter, and collaboration with the University of California at Santa Cruz (UCSC) on the Si tracker-DAQ interface.

II. ACCOMPLISHMENTS DURING THE GRANT PERIOD

Detector Monte Carlo Modelling: A detailed Monte Carlo model of the instrument was further refined during the grant period. This work was the principal responsibility of Dr. William Atwood (SLAC/UCSC). The model is an important tool for developing the analysis algorithms and triggers that allow descrimination of celestial gamma-rays from the much higher backgrounds due to cosmic-rays, earth albedo gamma-rays and trapped charged particles. The model also allows evaluation of the expected measurement performance of the full-size GLAST instrument (i.e., effective area, angular resolution, field-of-view, energy resolution).

Hardware Development: Significant progress on hardware development was also made during the report period in a number of areas:

Si-Tracker: The University of California at Santa Cruz (R. Johnson, et al.) developed the first working prototype of the the front-end VLSI electronics for the Si-strip detector readouts. Construction of a prototype tracker consisting of 6 tracking planes with 2 singlesided Si detectors (6 cm x 6 cm with 240 μm pitch) per plane was constructed during the grant period and was subsequently tested in a gamma-ray beam at SLAC (the Stanford Linear Accelerator Center) in October 1997. This prototype included a set of first-generation VLSI readout electronics with a simplified digital readout but with the complete analog front-end section that is required for the prototype module readout. The Stanford and UCSC groups began the joint development of the required interface between the tracker readout and the Data Acquisition System (DAQ) during this period.

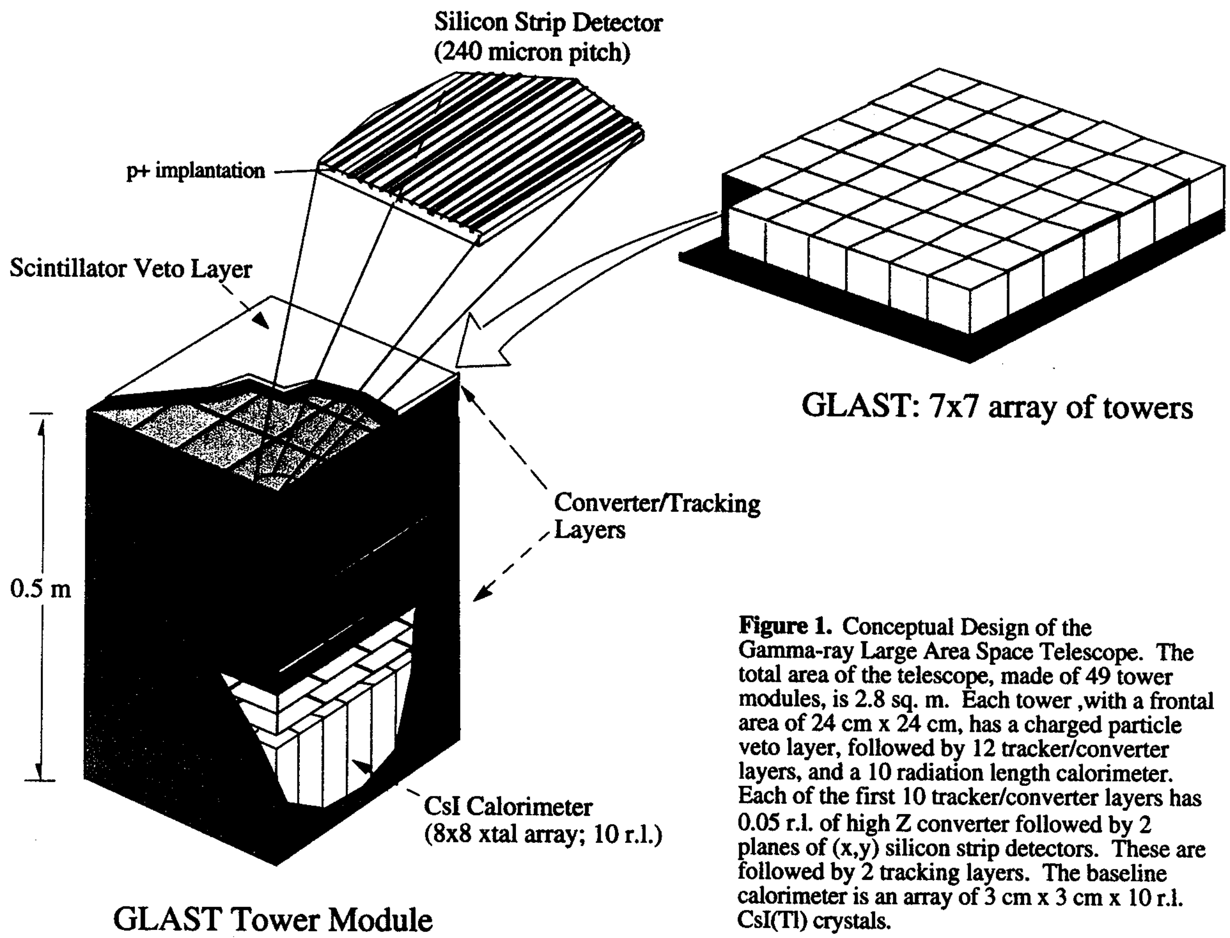

Figure 1. Conceptual Design of the Gamma-ray Large Area Space Telescope. The total area of the telescope, made of 49 tower modules, is 2.8 sq. m. Each tower ,with a frontal area of 24 cm x 24 cm, has a charged particle veto layer, followed by 12 tracker/converter layers, and a 10 radiation length calorimeter. Each of the first 10 tracker/converter layers has 0.05 r.l. of high Z converter followed by 2 planes of (x,y) silicon strip detectors. These are followed by 2 tracking layers. The baseline calorimeter is an array of 3 cm x 3 cm x 10 r.l. CsI(Tl) crystals.

Table 1: Comparison of GLAST and EGRET γ-Ray Telescope Parameters

	EGRET	GLAST
Energy range	30 MeV - 30 GeV	~ 10 MeV - 300 GeV
Energy resolution (eq. Gaussian σ @ 1 GeV)	9%	4.4%
Effective Area @ 1 GeV(2)	1200 cm^2	8000 cm^2
Solid Angle Acceptance (FWHM)	0.15 x π sr	0.82 x π sr
Single photon pos. error @ 1 GeV	1.5°	0.42°
Point Source Sensitivity(3)	8×10^{-8} ph cm^{-2} s^{-1}	2×10^{-9} ph cm^{-2} s^{-1}
Point Source Location	5-10 arcmin	0.5-1 arcmin
Volume	4.8 m^3	~ 2 m^3
Mass	1830 kg	~ 3000 kg
Power	190 W	~ 600 W
Lifetime	~ 5 yr	> 5 yr

The Stanford group also collaborated with UCSC, SLAC, and University of Tokyo on completing the detailed specification of the Si-strip detectors for the prototype module. Finally, mechanical prototypes (see Figure 2) of the Si-tracker planes were constructed to verify the mechanical and electrical integrity under vibration and thermal/vacuum loads expected during launch. No failures resulted under any of the test conditions, which exceeded NASA qualification standards.

Figure 2. Initial prototype tracker tray constructed to verify mechanical and electrical stability under vibration and thermal/vacuum loading. No failures resulted under any of the test conditions, which exceeded NASA qualification standards.

CsI Calorimeter: We worked with NRL to define the hardware requirements for a test calorimeter constructed for the Fall beam test at SLAC. The Stanford group procurred most of the hardware components for this calorimeter. Assembly was done by the NRL group.

Data Acquisition and Trigger System (DAQ): An important area of activity during the report period for the Stanford group has been on the development of the DAQ. This effort at Stanford has been led by Dr. Roger Williamson (Senior Engineering Research Associate), and has involved 1 graduate student, a part time technician, Prof. T. Burnett (a visiting professor from the Univ. of Washington), and Mr. James Wallace (design engineer). A level-1 trigger architecture was defined. We also baselined the requirements (data rates, processing requirments, etc.) for the DAQ, identified candidate hardware architectures, and began analysis (timing diagrams, etc.) of these architectures. We also began work on optimizing the pattern recognition algorithms used to discriminate gamma-ray events from cosmic-ray events and we developed and implemented optimal track fitting algorithms using Kalman filtering techniques. These algorithms were tested as part of the data analysis effort associated with the beam tests done at SLAC in October 1997. Figure 3 shows the results of applying this track-fitting algorithm to the beam test data. The agreement between the Monte Carlo model and the data is excellent and serves to verify the performance of the detectors and validates the Monte Carlo codes that are the basis of predicting the performance expected from the full-scale GLAST instrument.

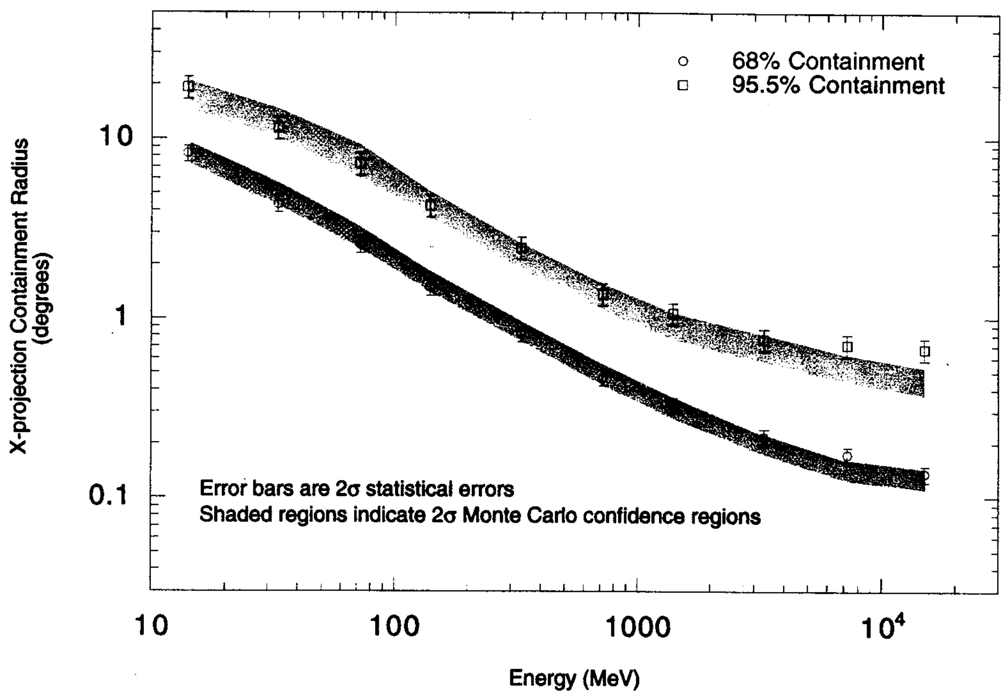

Figure 3. Energy dependence of the 68% and 95.5% projected containment radii determined from beamtest data for tracker configuration with 4% Pb converters and 3-cm spacing.