STUDYING THE HIGH-ENERGY GAMMA-RAY SKY WITH GLAST

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ABSTRACT

Building on the success of the Energetic Gamma Ray Experiment Telescope (EGRET) on the Compton Gamma Ray Observatory, the Gamma-ray Large Area Space Telescope (GLAST) will make a major step in the study of such subjects as blazars, gamma-ray bursts, the search for dark matter, supernova remnants, pulsars, diffuse radiation, and unidentified high-energy sources. The instrument will be built on new and mature detector technologies such as silicon strip detectors, low-power low-noise LSI, and a multilevel data acquisition system. GLAST is in the research and development phase, and one full tower (of 25 total) is now being built in collaborating institutes. The prototype tower will be tested thoroughly at SLAC in the fall of 1999.

1 INTRODUCTION

As the highest-energy photons, gamma rays have an inherent interest to astrophysicists and particle physicists studying high-energy, nonthermal processes. Gamma-ray telescopes complement those at other wavelengths, especially radio, optical, and X-ray, providing the broad, mutiwavelength coverage that has become such a powerful aspect of modern astrophysics. EGRET, the high-energy telescope on the Compton Gamma Ray Observatory, has led the way in such an effort, contributing to broad-band studies of blazars, gamma-ray bursts, pulsars, solar flares, and diffuse radiation. Now development is underway for the next significant advance in high-energy gamma-ray astrophysics, GLAST, which will have $\sim$30 times the sensitivity of EGRET at 100 MeV and more at higher energies, including the largely-unexplored 30–300 GeV band. The following sections describe the science goals, instrument technologies, and international collaboration for GLAST.

Some key scientific parameters for GLAST are shown in Table 1 (Bloom, 1996; Michelson, 1996).

Table 1: SOME GLAST CHARACTERISTICS

Energy Range	20 MeV – 300 GeV
Energy Resolution	10% (>100 MeV)
Effective Area	>8000 cm^2 (>1 GeV)
Field of view	>2.5 steradians
Source location determination	30 arc seconds to 5 arc minutes
Source sensitivity (1 yr.)	3 x 10^{-9} ph (E>100 MeV)/cm^2s
Mission life	> 2 years

2 SCIENTIFIC GOALS FOR GLAST

2.1 Blazars

Blazars are thought to be active galactic nuclei consisting of accretion-fed supermassive black holes with jets of relativistic particles directed nearly toward our line of sight. The formation, collimation, and particle acceleration in these powerful jets remain important open questions. Many blazars are seen as bright, highly-variable gamma-ray sources, with the high-energy gamma rays often dominating the luminosity (Hartman et al. 1997). For this reason, the gamma rays provide a valuable probe of the physics under these extreme conditions, especially when studied as part of multiwavelength campaigns (e.g. Shrader and Wehrle, 1997). With its wide field of view and high sensitivity, GLAST will enable blazar studies with far better resolution and time coverage than was possible with EGRET. GLAST should detect thousands of blazars.

Blazars are often very distant objects, and the extension of the gamma-ray spectrum into the multi-GeV range opens the possibility of using blazars as cosmological probes. In the energy range beyond that observed by EGRET but accessible to GLAST, the blazar spectra should be cut off by absorption effects of the extragalactic background light produced by galaxies during the era of star formation. A statistical sample of high-energy blazar spectra at different redshifts may provide unique information on the early universe (Macminn and Primack, 1996).

2.2 Gamma-Ray Bursts

The recent breakthrough associating gamma-ray bursts with distant galaxies (e.g. Djorgovski et al. 1997) has changed the focus of gamma-ray burst research from the question of where they are to the questions of what they are and how they work. The power source and emission mechanisms for gamma-ray bursts remain mysteries. The high-energy gamma radiation seen from some bursts by EGRET (Dingus et al. 1995) indicates that GLAST will provide important information about these questions. With its large field of view, GLAST can expect to detect over 100 bursts per year at GeV energies compared to about one per year for EGRET, allowing studies of the high-energy component of the burst spectra.

2.3 Search for Dark Matter

One of the leading candidates for the dark matter now thought to dominate the universe is a stable, weakly-interacting massive particle (WIMP). One candidate in supersymmetric extensions of the standard model in particle physics is the neutralino, which might annihilate into gamma rays in the 30-300 GeV range covered by GLAST (see Jungman, Kamionkowski and Griest, 1996, for a general discussion of dark matter candidates). The good energy resolution possible with the GLAST calorimeter will make a search for such WIMP annihilation lines possible.

2.4 Pulsars

A number of young and middle-aged pulsars have their energy output dominated by their gamma-ray emission. Because the gamma rays are directly related to the particles accelerated in the pulsar magnetospheres, they give specific information about the physics in these high magnetic and electric fields. Models based on the EGRET-detected pulsars make specific predictions that will be testable with the larger number of pulsars that GLAST's greater sensitivity will provide (Thompson, et al. 1997).

2.5 Supernova Remnants and the Origin of Cosmic Rays

Although a near-consensus can be found among scientists that the high-energy charged particle cosmic rays originate in supernova remnants (SNR), the proof of that hypothesis has remained elusive. Some EGRET gamma-ray sources appear to be associated with SNR, but the spatial and spectral resolution make the identifications uncertain (e.g. Esposito et al. 1996). If SNR do accelerate cosmic rays, they should produce gamma rays at a level that can be studied with GLAST, which will be able to resolve some SNR spatially.

2.6 Diffuse Gamma Radiation

Within the Galaxy, GLAST will explore the diffuse radiation on scales from molecular clouds to galactic arms, measuring the product of the cosmic ray and gas densities. The extragalactic diffuse radiation may be resolved; GLAST should detect all the blazars suspected of producing this radiation. Any residual diffuse extragalactic gamma rays would have to come from some new and unexpected source.

2.7 Unidentified Sources and New Discoveries

Over half the sources seen by EGRET in the high-energy gamma-ray sky remain unidentified with known astrophysical objects. Some may be radio-quiet pulsars, some unrecognized blazars, and some are likely to be completely new types of object (for a recent discussion, see Mukherjee et al., 1997). In general, the EGRET error boxes are too large for spatial correlation, and the photon density is too small for detailed timing studies. Both these limitations will be greatly alleviated with GLAST. In particular, the combination of GLAST with the next generation of X-ray telescopes should resolve a large part of this long-standing mystery. The new capabilities of GLAST will surely produce unanticipated discoveries, just as each previous generation of gamma-ray telescope has done.

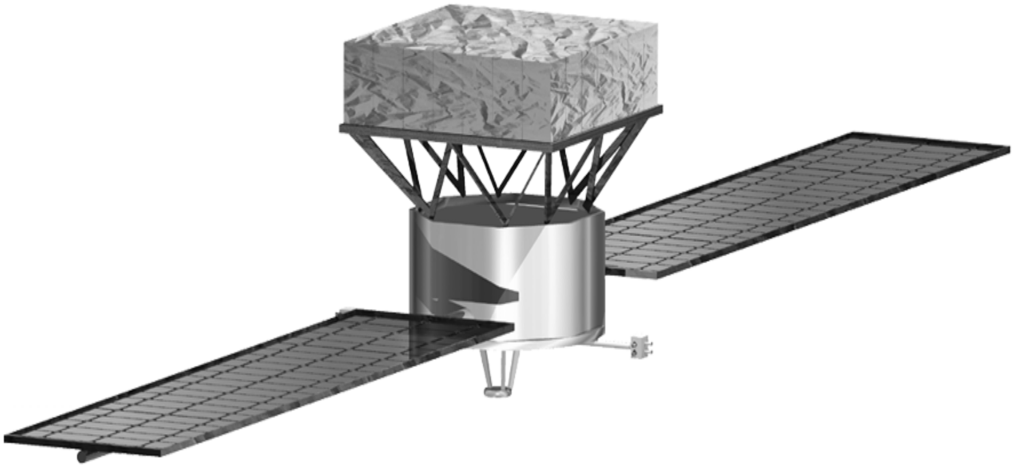

Figure 1: A visualization of the proposed GLAST instrument and spacecraft. The picture shows the current baseline instrument consisting of 25 tower modules.

3 GLAST HARDWARE DEVELOPMENT

3.1 Glast Technologies

Any high-energy gamma-ray telescope operates in the range where pair production is the dominant energy loss process; therefore, GLAST (see Fig. 1 for one concept configuration) shares some design heritage with SAS-2, COS-B, and EGRET: it has a plastic anticoincidence system, a tracker with thin plates of converter material, and an energy measurement system. What GLAST benefits from most is the rapid advance in semiconductor technology since the previous gamma-ray missions. The silicon revolution affects GLAST in two principal ways as will be described below.

3.1.1 Multi-Layer Si Strip Tracker

The tracker consists of solid-state devices instead of a gas/wire chamber. The baseline design for GLAST uses Si strip detectors with 195 μm pitch (see Fig. 2), offering significantly better track resolution with no expendable gas or high voltage discharge required. Low-power application specific integrated circuits (ASICs) allow readout of approximately 10^6 channels of tracker with only 260 W.

The 77 m^2 of Si strip detectors planned for GLAST will be the largest Si strip detector system ever made. Since manufacturers (Hamamatsu, Micron and others) have decided to move to 6-inch wafers, we can expect a good cost/performance.

3.1.2 On-board Computer

On-board computing, which was extremely limited in the Compton Observatory era, is now possible on a large scale. The 32-bit, radiation-hard processors now available allow software to replace some of the hardware triggering of previous missions and also enable considerable on-board analysis of the tracker data to enhance the throughput of useful gamma-ray data.

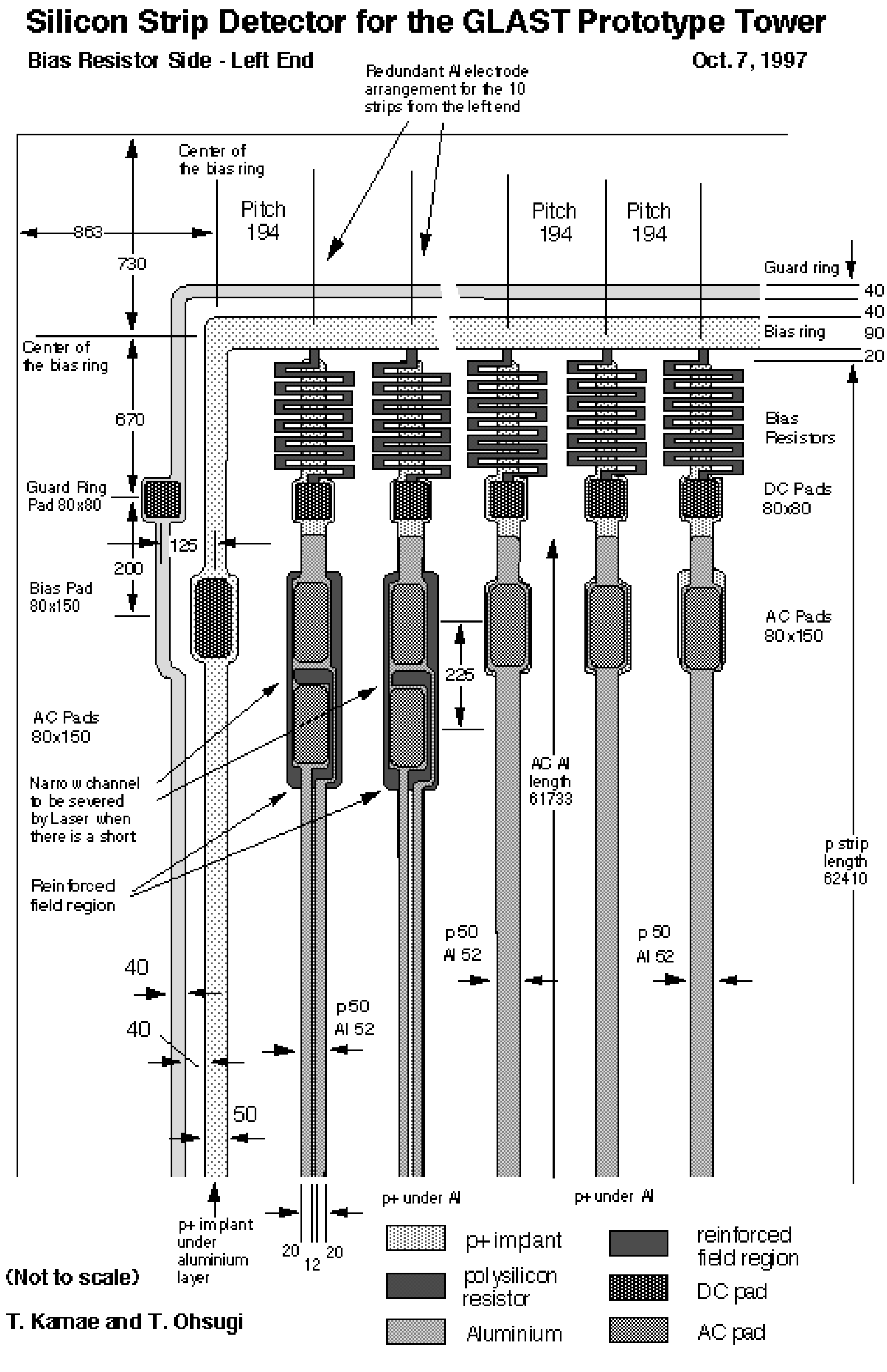

Figure 2: Silicon Strip Detector for the GLAST Prototype Tower. The linear dimension is in μm.

3.2 Plan and Schedule

Two prototype Si strip detectors have been made. The first prototype was a 6-cm-detector. The second prototype (Fig. 2), which had redundancy strips and bypass strips, showed superb characteristics (bad strips $< 0.03\%$). A third prototype, made from 6-inch-wafer, is being requested.

A "mini-tower" consisting of a stack of the 6 cm Si strip detectors, a CsI(Tl) calorimeter, and a plastic scintillator anticoincidence, was tested at a tagged gamma-ray beam at SLAC in Fall, 1997 (Ritz, et al., 1998). A full prototype tower will be built by summer, 1999, for the Fall, 1999, beam test. We are expecting full production of the GLAST hardware to begin in 2001. We are currently waiting for approvals from DOE and NASA. We will also apply for the grant-in-aids from Monbusho (the Ministry of Education of Japan).

4 THE GLAST COLLABORATION

GLAST is planned as a facility-class mission involving an international collaboration of the particle physics and astrophysics communities. Currently, scientists from the United States, Japan, France, Germany, and Italy are involved in the development effort. GLAST is currently listed as a candidate for a new start at NASA, with a possible launch in 2005. Further information about GLAST can be found at

http://www-glast.stanford.edu/

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