GLAST -> Fermi: Building an International Science Team and the Path to Mission Approval

Peter F. Michelson

Fermi LAT Collaboration Meeting

Pisa, Italy

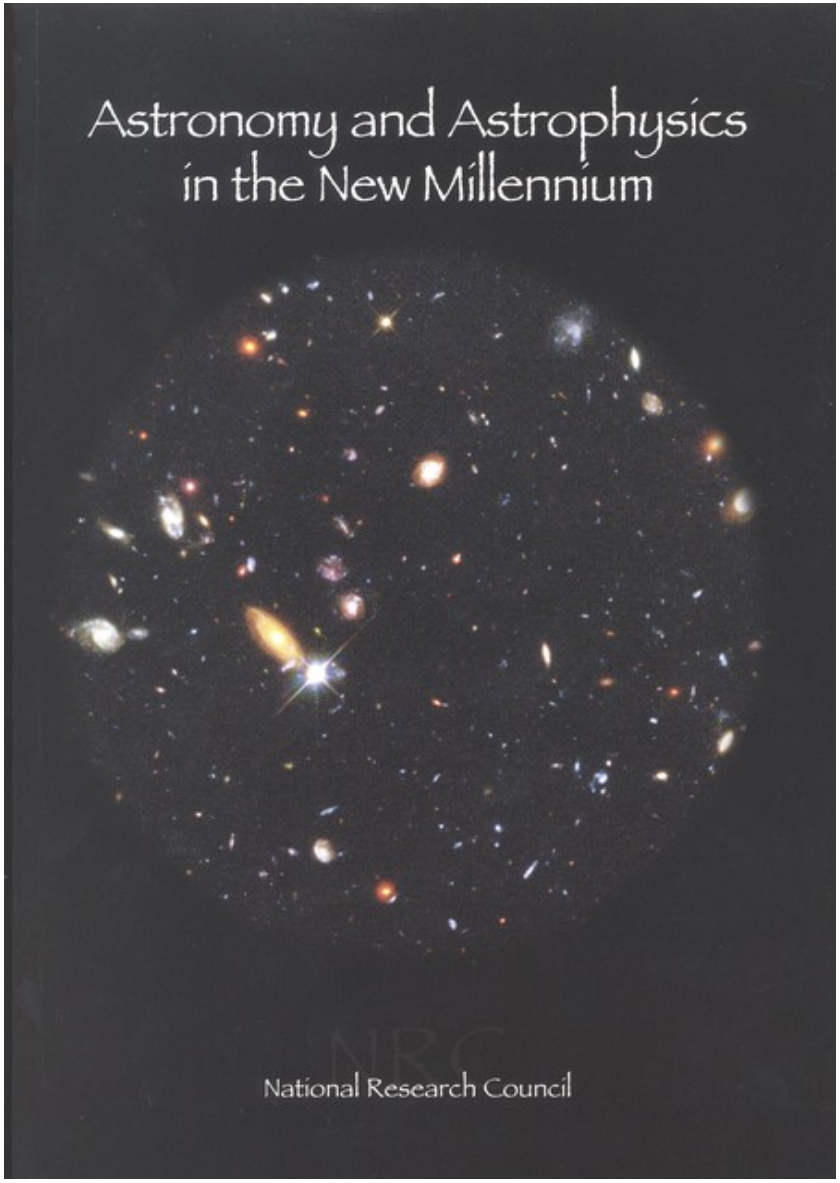
March 12-16, 2018

Key Requirements

- Broad support from Science Community
- Dedicated science instrument team

* desirable goal: minimize bureaucracy

A Key Milestone: GLAST named a priority by National Research Council 2000 Decadal Survey of Astronomy & Astrophysics



ASTRONOMY AND ASTROPHYSICS SURVEY COMMITTEE

CHRISTOPHER F. McKEE, University of California, Berkeley, *Co-chair*
JOSEPH H. TAYLOR, JR., Princeton University, *Co-chair*
DAVID J. HOLLENBACH, NASA Ames Research Center, *Executive Officer*
TODD BOROSON, National Optical Astronomy Observatories
WENDY FREEDMAN, Carnegie Observatories
DAVID C. JEWITT, University of Hawaii
STEVEN M. KAHN, Columbia University
JAMES M. MORAN, JR., Harvard-Smithsonian Center for Astrophysics
JERRY E. NELSON, University of California Observatories
R. BRUCE PARTRIDGE, Haverford College
MARCIA RIEKE, University of Arizona
ANNEILA I. SARGENT, California Institute of Technology
ALAN TITLE, Lockheed-Martin Space Technology Center
SCOTT TREMAINE, Princeton University
MICHAEL S. TURNER, University of Chicago

PANEL ON HIGH-ENERGY ASTROPHYSICS FROM SPACE

ROGER D. BLANDFORD, California Institute of Technology, *Chair*
STEVEN M. KAHN, Columbia University, *Vice Chair*
LARS BILDSTEN, University of California, Berkeley
FRANCE A. CORDOVA, University of California, Santa Barbara
JONATHAN GRINDLAY, Harvard-Smithsonian Center for Astrophysics
DAN McCAMMON, University of Wisconsin
PETER MICHELSON, Stanford University
STEPHEN S. MURRAY, Harvard-Smithsonian Center for Astrophysics
RENE ASHWIN ONG, University of Chicago
CRAIG L. SARAZIN, University of Virginia
NICHOLAS WHITE, NASA Goddard Space Flight Center
STANFORD EARL WOOSLEY, University of California, Santa Cruz

TABLE ES.1 Prioritized Initiatives (Combined Ground and Space) and Estimated Federal Costs for the Decade 2000 to 2010[a,b]

Initiative	Cost[c] ($M)
Major Initiatives	
Next Generation Space Telescope (NGST)[d]	1,000
Giant Segmented Mirror Telescope (GSMT)[d]	350
Constellation-X Observatory (Con-X)	800
Expanded Very Large Array (EVLA)[d]	140
Large-aperture Synoptic Survey Telescope (LSST)	170
Terrestrial Planet Finder (TPF)[e]	200
Single Aperture Far Infrared (SAFIR) Observatory[e]	100
Subtotal for major initiatives	2,760
Moderate Initiatives	
Telescope System Instrumentation Program (TSIP)	50
Gamma-ray Large Area Space Telescope (GLAST)[d]	300
Laser Interferometer Space Antenna (LISA)[d]	250
Advanced Solar Telescope (AST)[d]	60
Square Kilometer Array (SKA) technology development	22
Solar Dynamics Observatory (SDO)	300
Combined Array for Research in Millimeter-wave Astronomy (CARMA)[d]	11
Energetic X-ray Imaging Survey Telescope (EXIST)	150
Very Energetic Radiation Imaging Telescope Array System (VERITAS)	35
Advanced Radio Interferometry between Space and Earth (ARISE)	350
Frequency Agile Solar Radio telescope (FASR)	26
South Pole Submillimeter-wave Telescope (SPST)	50
Subtotal for moderate initiatives	1,604
Small Initiatives	
National Virtual Observatory (NVO)	60
Other small initiatives[f]	246
Subtotal for small initiatives	306
DECADE TOTAL	4,670

Milestones toward selection of GLAST mission

Elliott Bloom Bill Atwood

- ✦ Early 1992 first discussions at Stanford and SLAC
  - Early concepts (Si + scintillator), initial spacecraft accommodation study, …
- ✦ Aug 1992 NASA Supporting Research & Technology Program (1+2 years, $300k total)
  - Simulations, particularly to optimize Si tracker design; Si FEE work

Guido Barbiellini

- ✦ Aug 1994 first GLAST workshop at Stanford/SLAC (~50-100 attendees)
  - "Towards a Next Generation High-Energy Gamma-Ray Telescope"
- ✦ 1994 NASA Advanced Mission Concept Study (1-year program)
  - Team largely in place: Stanford & SLAC, NRL, UCSC, INFN, Univ Tokyo, and others
- ✦ 1995 NASA SR&T (3-year program, $2M total)
  - First major funding for prototype hardware (tracker, calorimeter, anti-coincidence); GSFC joins

- ✦ 1997 GLAST is future mission in NASA Structure & Evolution of Universe Science Roadmap and Space Science Strategic Plan
- ✦ 1998 NASA GLAST Instrument Technology Development Program
  - Two concepts
    - ✦ GLAST (i.e. LAT)
    - ✦ SIFTER, FiberGLAST
- ✦ 1999 NASA GLAST Flight Investigations Announcement of Opportunity
  - Selected in 2000 for flight mission

The GLAST Instrument Technology Development Program supports the advancement of spacecraft-based instrument technology that shows promise for use in gamma-ray measurement investigations on the GLAST mission. The goal of the program is not to develop flight-qualified hardware, but to develop and demonstrate technologies for gamma-ray measurement with scientific instruments or components of such instruments to the point where the instruments may

Early history

Within one day of first GLAST concept, Monte Carlo was set up

I. A Brief History

In the *beginning* GLAST was:

- 10 x 10 Array of Towers
- 18 cm long SSD Ladders
- simple pixel CsI 10 X_0 Calorimeter
- a .5 X_0 Deep Tracker
- SSD ACS

In 1994 during trip to Japan and discussions with Akimov GLAST became:

- 7 x 7 Array of Towers (to fit inside a SOYUS)
- 24 cm long SSD Ladders (confident about S/N)
- Scintillation tile ACS (good tracking not required)

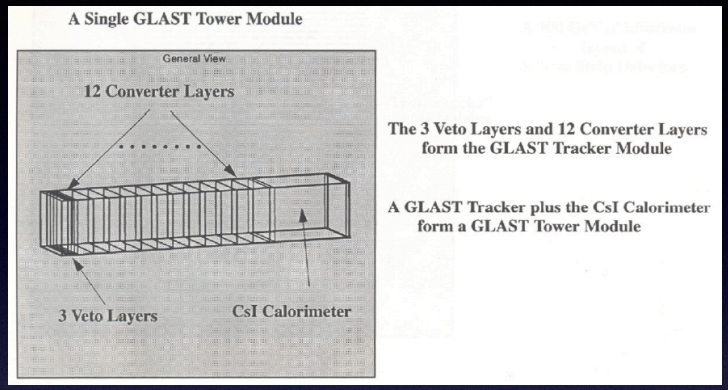
In 1997, faced with actually BUILDING a prototype Tower a first pass at optimizing the GLAST design was done. GLAST became:

- 5 x 5 Array of Towers
- 32 cm long SSD Ladders (FEE in hand)
- Imaging Calorimeter

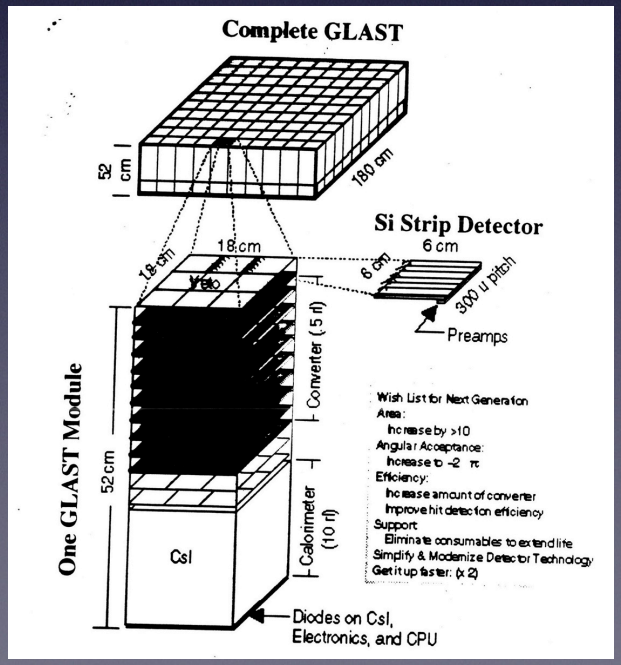
GSFC Sept-97 2 Bill Atwood

Final GLAST design

- 4x4 array of towers
- 37-cm long SSD ladders (9.2 cm wafers)
- Imaging calorimeter



In the beginning… **August 1992**



X

GLAST Flight Proposal – submitted in response to NASA AO, November 1999

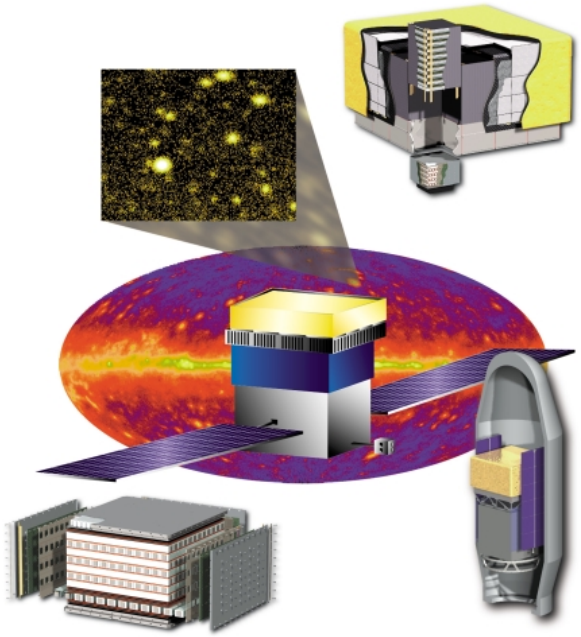
Response to AO 99-OSS-03

GLAST LARGE AREA TELESCOPE

Flight Investigation:

An Astro-Particle Physics Partnership
Exploring the High-Energy Universe

Volume 1: Scientific and Technical Plan



November 1999

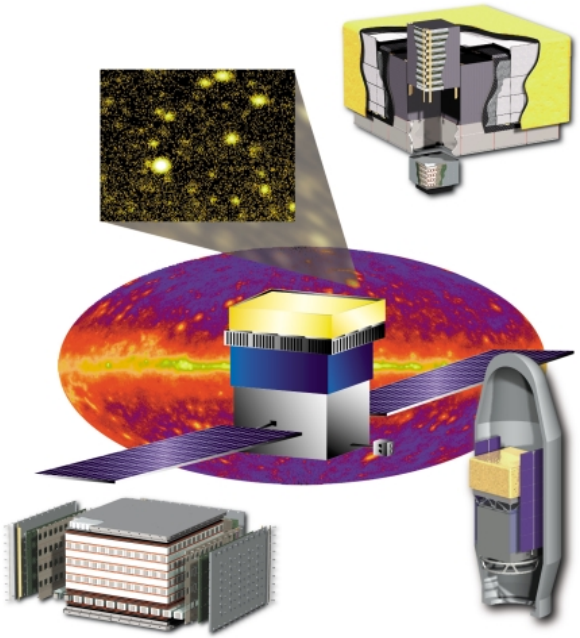
Response to AO 99-OSS-03

GLAST LARGE AREA TELESCOPE

Flight Investigation:

An Astro-Particle Physics Partnership
Exploring the High-Energy Universe

Volume 2: Cost and Management Plan



November 1999

GLAST Selection: Strong International Partnerships crucial

STANFORD LINEAR ACCELERATOR CENTER

Operated for the U.S. Department of Energy by Stanford University

Professor Jonathan Dorfan
Director

P.O. Box 4349, MS 75
Stanford, CA 94309 USA

October 29, 1999

Dr. Alan Bunner
Science Program Director
Structure and Evolution of the Universe
Office of Space Science
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Alan:

I write to you to pledge, in the strongest terms, my and SLAC's support for the GLAST proposal described in the attached documents. I believe the proposal is responsive to the requirements of the NASA GLAST AO, and that the collaboration is well constituted and amply supported to deliver a quality instrument on a schedule well matched to the earliest possible launch date.

SLAC's participation is made possible by the DOE's substantial commitment of $35M towards the fabrication of the experiment and around $7M per year for the operations phase.

The Laboratory is fully committed to providing the oversight, personnel, infrastructure and management tools required to construct GLAST. SLAC has an outstanding record of on-time, on-budget management of large construction projects. The B Factory machine and detector, a facility which comprised $300M of construction involving multiple DOE Laboratories and nine nations was recently completed on budget and ahead of schedule. Both the machine and detector are performing excellently and, within six weeks of coming online, the B Factory created a world record in peak luminosity and integrated data logged. We are fully committed to managing GLAST in the same professional manner which has led to our previous successes.

We are aggressively assembling the team of engineers, scientists and support staff needed to successfully carry out GLAST. In building this team, we have drawn from our best technical staff and most experienced managers. In areas where we lack space-based experience, we are hiring the appropriate talent. We have been most fortunate to attract to SLAC, Bill Althouse who has taken on the role of GLAST Project Manager. Bill has more than 25 years of experience working with NASA that are directly applicable to the GLAST project. We are also building a strong system engineering team to support the GLAST instrument development. We have arranged for Professor Tuneyoshi Kamae to come to SLAC from Japan to take on the role of Instrument Technical Manager. Currently, the Acting Instrument System Engineer is the Chief Engineer of the Research Division. We expect that our offer to an outstanding candidate for the position of Instrument System Engineer will soon be accepted. We have dedicated a 12,000 square foot assembly building, complete with overhead crane coverage, to the GLAST project. The breadth and depth of our substantial human and physical infrastructure provide significant ballast and risk amelioration should the project experience technical or schedule difficulties.

SLAC, along with the DOE, are immensely excited by the scientific program of the GLAST mission. If selected, we welcome the opportunity to participate in the development of GLAST with a longer term commitment to provide the data processing capabilities which will be critical to producing the science. Encouraged by the excitement of GLAST, I will seek further opportunities for SLAC to participate in space-based ventures.

Yours sincerely,

Jonathan Dorfan
Director, SLAC

cc: Peter Rosen
John O'Fallon
David Leith
Peter Michelson
Bill Althouse
Tuneyoshi Kamae

Jonathan Dorfan

Burton Richter

ISTITUTO NAZIONALE DI FISICA NUCLEARE
IL PRESIDENTE

ROMA (Italy)
Piazza dei Caprettari, 70 (00186)
Tel. 06-6840031
Fax 06-68307924

29 OTT. 1

Prot. n. 3985/ 12.32/

Prof. Peter F. Michelson
Department of Physics
Stanford University

Stanford, CA 94305

Prof. Jonathan Dorfan
Director
Stanford Linear Accelerator Center

RE: Italian Participation in GLAST Investigation

Dear Prof. Michelson and Prof. Dorfan,

The INFN recognizes and encourages the interest of Italian scientists to participate in the GLAST Large Area Telescope (LAT) investigation. We recognize that Italian scientists, particularly Prof. Guido Barbiellini, have been actively involved in the planning of the GLAST investigation from the beginning. We endorse their continuing participation in the Formulation Phase planning.

We are very much interested about the important opportunity that GLAST will bring to the science community. GLAST will address fundamental issues about how particles are accelerated to high-energies in Nature and about the physical mechanisms operating in gamma-ray bursts, the most powerful explosions in the Universe.

INFN is looking forward to receiving soon a formal proposal from Italian scientists for participation in the Construction and Science Phases of the project. As you know, a nucleus of our scientists have been involved in the R & D phase. They are working now to enlarge the group in order to support a significant Italian role in both the flight instrument and the science investigation at a level comparable to the larger of the non-US partners in GLAST. Among several possible roles within the construction project, a substantial involvement in the GLAST silicon tracker is expected. Our laboratories have expertise in all aspects of this critical technology and have a history of successful collaboration with SLAC and experience in space experiments.

Our formal review process to confirm our participation in the construction and science phase is beginning now and we expect it to conclude by June 2000, subject to NASA selection of your proposal. We also understand that the GLAST mission is subject to formal confirmation by NASA before the start of the construction phase.

We also recognize the proposed contribution of the Italian Space Agency, ASI, to the project. For the GLAST instrument and science investigation these will be captured in an MoU with Stanford/SLAC and for those concerning support of the mission, as the use of the Malindi ground station for telemetry/reception, through an MoA between NASA and ASI.

Enzo Iarocci

c.c.: Prof. David Leith, Research Director, SLAC
Prof. Giovanni F. Bignami, ASI Science Director
Prof. Angelo Scribano, INFN G.E.

Enzo Iarocci

agenzia spaziale italiana

Professor Peter F. Michelson
Department of Physics
Stanford University
Stanford, CA 94305
USA

7 OTT. 1999
prot. 835.99/189

Re: ASI Endorsement of Italian Participation in GLAST Investigation

ASI is delighted to endorse participation by Italian scientists in your GLAST Large Area Telescope investigation. ASI has reviewed the proposed investigation and found it to be of the highest quality science, of direct interest to the Italian astronomical community.

In particular, ASI will make every effort towards the following contributions:

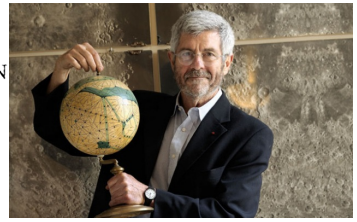
1. In cooperation with INFN, support Italian scientists to participate in the GLAST science investigation.
2. Use of the Malindi ground station for GLAST mission telemetry reception.

ASI offers the use of the Malindi ground station to NASA as part of the overall Italian participation in your proposed investigation, contingent on NASA's selection of your investigation and a final scientific review of the negotiated agreement between ASI and NASA. ASI will also work in partnership with the Istituto Nazionale di Fisica Nucleare (INFN) to support the overall scientific participation of the Italian scientific community at large.

G. F. Bignami

Giovanni F. Bignami
ASI Science Director

Copy to: Prof. Enzo Iarocci, President, INFN
Prof. Angelo Scribano, Vice-President, INFN
Dr. Alan Bunner, NASA Headquarters
Dr. Donald Kniffen, NASA Headquarters
Prof. Jonathan Dorfan, Director, SLAC
Prof. David Leith, Research Director, SLAC



SEDE
Via di Villa Patrizi, 13
00161 Roma - Italia
Tel. (39.6) 4404.205/206/051/054

UFFICI
Viale Regina Margherita, 202
00198 Roma - Italia
Tel. (39.6) 8567.9

CENTRO DI GEODESIA SPAZIALE
Località Terlecchia - C.P. 11
75100 Matera - Italia
Tel. (39.835) 3779

BASE LANCIO PALLONI STRATOSFERICI
S.S. 113 N. 174 Contrada Milo
91100 Trapani - Italia
Tel. (39.923) 539928/539036/553800/553484

VETENSKAP OCH KONST
KUNGL TEKNISKA HÖGSKOLAN

Royal Institute of Technology
Physics Department
Frescativägen 24
10405 Stockholm, Sweden

October 11, 1999

Professor Peter Michelson
Physics Department
Stanford University
Stanford, CA 94305-4060

Dear Professor Michelson:

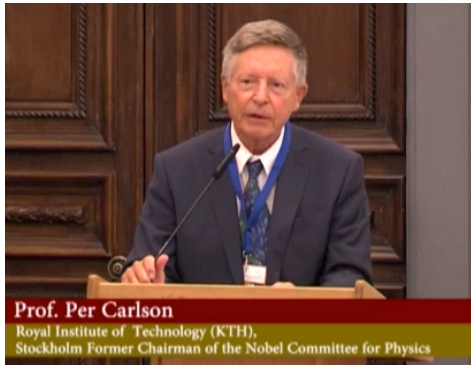
The Royal Institute of Technology (KTH), Stockholm, Sweden, is pleased to be part of the GLAST primary instrument proposal which will be submitted by Stanford University in response to NASA's Announcement of Opportunity for the Gamma Ray Large Area Telescope (AO 99-OSS-03). The KTH group is one of three groups in Stockholm forming a joint Stockholm participation in GLAST. We are committed to providing the necessary support to help insure the success of the proposed investigation. In this effort KTH co-investigators Per Carlson and Tom Francke together with engineering staff and students is responsible for the purchase and tests of the CsI calorimeter elements for the calorimeter subsystem for GLAST. The necessary funding for our participation is requested from the Knut and Alice Wallenberg Foundation. The associated support for KTH participation has been submitted to you for inclusion in your cost proposal.

KTH has a long and successful history in high-energy physics and astrophysics experiments including investigations of elementary particle interactions at the world leading CERN laboratory and the successful CAPRICE balloon missions. We look forward to our involvement with the international team you have assembled for GLAST and anticipate the significant advances that it will provide.

Sincerely,

P Carlson

Per Carlson
Professor of physics, department chair



National Aeronautics and
Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

NOV 01 1999

Reply to Attn of: 660

Professor Peter Michelson
Stanford University
Department of Physics
Stanford, CA 94305-4060

Dear Professor Michelson:

I am personally excited about the Goddard Space Flight Center (GSFC) joining you in your proposal to build the Large Area Telescope (LAT) instrument for the Gamma Ray Large Area Space Telescope (GLAST). I anticipate this mission will make a tremendous advance in high-energy gamma ray astronomy and will be a key component in fulfilling the Structure and Evolution of the Universe (SEU) strategic plan. We expect the astrophysics community at large will be excited to have this new high-energy waveband opened for study of the most energetic processes in nature.

Our scientific and technical staff has worked closely with you and the GLAST LAT team in developing the instrument concepts and the scientific rationale for the mission. The GSFC will develop and build the Anti-Coincidence Detector (ACD) subsystem, the instrument thermal blanket/micrometeorite shield, and the balloon flight test. We will also provide key members of the instrument's leadership team, including the Instrument Scientist and the Chair of the Senior Scientist Advisory Committee. I believe that GSFC's expertise in the development of flight instrumentation for gamma-ray experiments will prove valuable to your team.

In conclusion, I assure that the scientific, engineering, management, facility, and other support that is necessary for the on time and within budget delivery of the ACD, thermal blanket/micrometeorite shield and balloon flight will be available and committed to the LAT. Our staff looks forward to working with you and your team, and we wish you well in this proposal.

Sincerely,

A.V. Diaz
Director

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
4555 OVERLOOK AVE SW
WASHINGTON D C 20375-5320

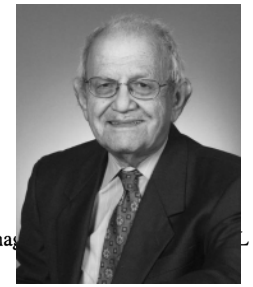
IN REPLY REFER TO:
3910
Ser 7650/150
19 Oct 99

Stanford University
Physics Department
Stanford, CA 94305-4060
Attn: Professor Peter F. Michelson

Dear Professor Michelson:

The Naval Research Laboratory (NRL) is pleased to submit proposal T-198-00 to be part of the GLAST primary instrument proposal which will be submitted by Stanford University in response to NASA's Announcement of Opportunity for the Gamma Ray Large Area Telescope (AO 99-OSS-03). We are committed to providing the necessary support to help insure the success of the proposed investigation. In particular, as detailed in the Work Breakdown Structure, NRL expects to provide the lead role in the development and delivery of the calorimeter subsystem for GLAST and to provide computer, instrument data bus, and spacecraft interface unit designs, hardware and software for the GLAST data acquisition system. In this effort, NRL co-investigators, W. Neil Johnson and J. Eric Grove will support the calorimeter. Co-investigators, Kent S. Wood and Michael Lovellette will support the data acquisition system efforts. The associated support for NRL participation has been submitted to you for inclusion in your cost proposal. It is our expectation that NRL will be funded directly by a NASA Defense Purchase Request for our responsibilities in the GLAST program.

NRL has a long and successful history in high-energy astrophysics missions including HEAO, SMM, CGRO/OSSE, and ARGOS/USA. We look forward to our involvement with the international team you have assembled for GLAST and anticipate the significant advances beyond CGRO/EGRET that it will provide.



Sincerely,

Herbert Gursky
By direction of the Commanding Officer

NRL Calorimeter Manag[illegible] DAQ Manager

W. Neil Johnson
Gamma & Cosmic Ray Astrophysics Branch

Kent S. Wood
X-ray Astronomy Branch

Department of Physics
University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo, JAPAN 113-0033

Professor Peter Michelson
Principal Investigator of GLAST, Physics Department, Stanford University
Stanford, CA94305-4060
USA

Professor Jonathan Dorfan
Director, Stanford Linear Accelerator Center
P.O.Box 4349, Stanford, CA 94309
USA

October 15, 1999

Dear Professors Michelson and Dorfan:

Re: Funding prospect for the Japanese GLAST collaboration

Representing the Japanese GLAST Team (we refer to this as JAPAN GLAST Consortium), we wish to inform you, in this letter, of our institutional and individual membership, and our plan for funding and sharing of responsibility, in the construction and operation phases of the project.

(1) Participating institutions and their scientific staffs

At the present the following institutes have expressed their intent to join Japan GLAST Consortium. Included in the list are the collaborating staff members and their titles.

Affiliation		Name	Title
Univ. of Tokyo	Dept. of Physics	Tuneyoshi KAMAE	Professor
		Yasushi FUKAZAWA	Instructor
	Inst. Cosmic Ray Res.	Tadashi KIFUNE	Professor
		Masaki MORI	Assoc. Professor
		Ryoji ENOMOTO	Assoc. Professor
Hiroshima Univ.	Dept. of Physics	Takashi OHSUGI	Professor
		Katsuichi YOSHIDA	Instructor
Inst. Space Astronautical Sciences		Tadayuki TAKAHASHI	Assoc. Professor
		Masanobu OZAKI	Instructor

It is our understanding that a Memorandom of Agreement will be signed between you (the GLAST PI and the SLAC Director) and us about the membership of the collaboration, funding, responsibility sharing, and other important issues, after the AO selection is made in our favor. We also understand that all works Japan GLAST Consortium participates is a part of the entire GLAST collaborative effort and that we are expected to follow coordination and guidance given by you, the GLAST PI and the SLAC Director.

Sincerely yours,

Tadashi KIFUNE
Professor
ICRR
Univ. of Tokyo

Takashi OHSUGI
Professor
Dept. of Physics
Hiroshima U.

Tadayuki TAKAHASHI
Assoc. Professor
ISAS

Tuneyoshi KAMAE
(Contact Person)
Professor
Dept. of Physics
Univ. of Tokyo
Hongo 7-3-1
Bunkyo-ku, Tokyo
JAPAN 113-0033
(Tel: 81-3-5841-4204)
(Fax: 81-3-5841-4158)

From: Bonneville Richard <Richard.Bonneville@cnes.fr>
To: "'Peter F. Michelson'" <peterm@Stanford.EDU>
Cc: "'Joubert Martine'" <Martine.Joubert@cnes.fr>,
    "'Grenier Isabelle'" <isabelle.grenier@cea.fr>
Subject: RE: GLAST
Date: Wed, 13 Jun 2001 12:39:03 +0200

Dear prof. Michelson,

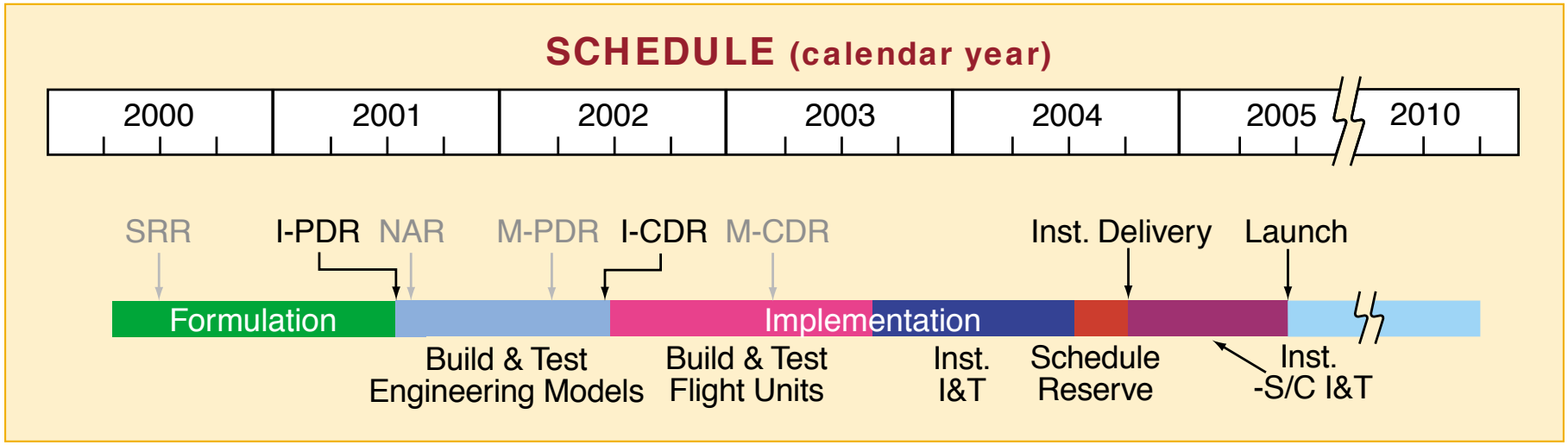
I am pleased to inform you that **our science program committee has issued a very positive recommendation** about the French participation to GLAST. The official minutes are not available yet, but I already know the rough content. The CNES support for 2001 has been secured and we are presently writing the file with the detailed budget request for the following phases up to launch. **The recommendation of the committee** (together with the efficient lobbying of our partners from the French research institutes) **is the green light that we needed**.

Best wishes

_____

Richard BONNEVILLE
Centre National d'Etudes Spatiales
Direction des Programmes et des Affaires Industrielles
Délégation à l'Etude et l'Exploration de l'Univers

Flight Proposal Schedule – November 1999



launch – June 2005

March 2000- NASA selected GLAST Collaboration Flight proposal

Ed Weiler, NASA Associate Administrator, Science Missions Directorate

GLAST is an International Mission

Multi-agency Partnership on LAT

LAT is being built by an international team

- Stanford University (SLAC & HEPL, Physics)
- Goddard Space Flight Center
- Naval Research Laboratory
- University of California, Santa Cruz
- University of Washington
- Ohio State University
- CEA/Saclay & IN2P3 (France)
- ASI & INFN (Italy)
- Hiroshima University, ISAS, RIKEN (Japan)
- Royal Inst. of Technology & Stockholm Univ. (Sweden)

GBM is being built by US and Germany

- MPE, Garching (Germany)
- Marshall Space Flight Center

Spacecraft and integration - Spectrum Astro

Mission Management: NASA/GSFC


Sweden


Italy

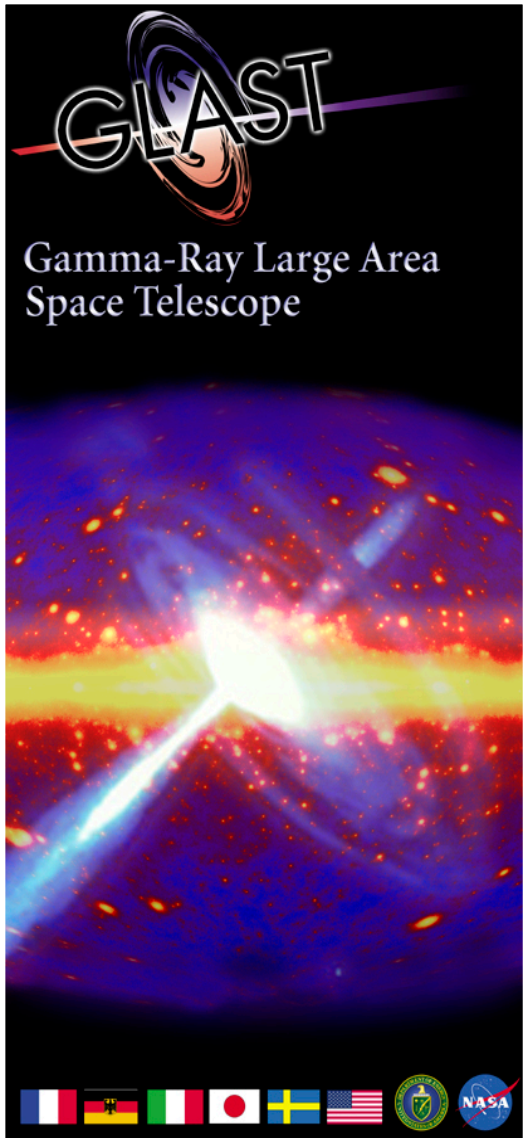

France


Germany


USA


Japan

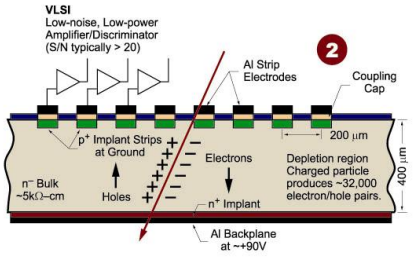
2001 Presentation

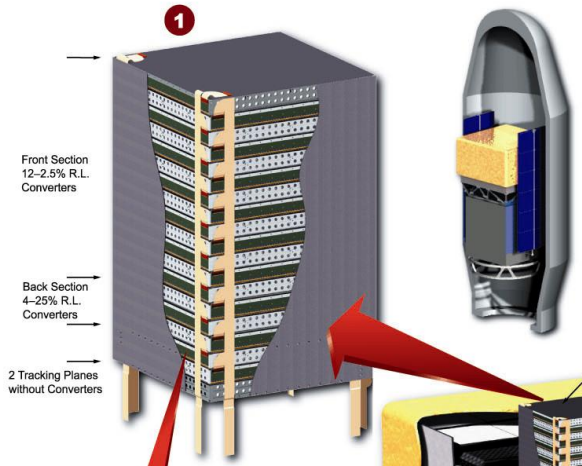


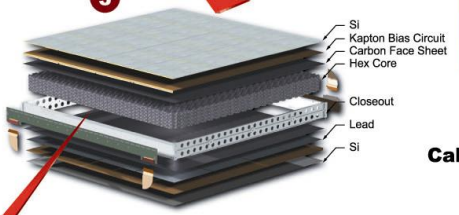
The GLAST LAT Instrument

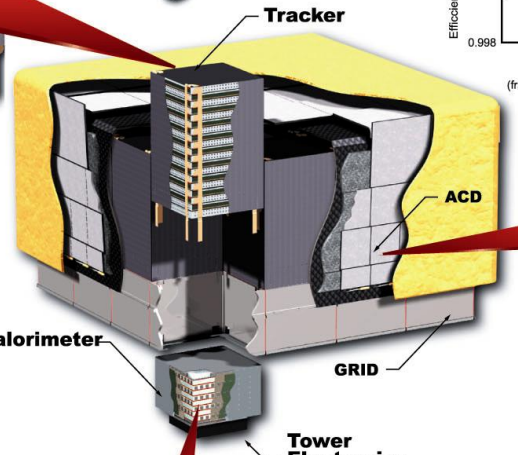
Tracker

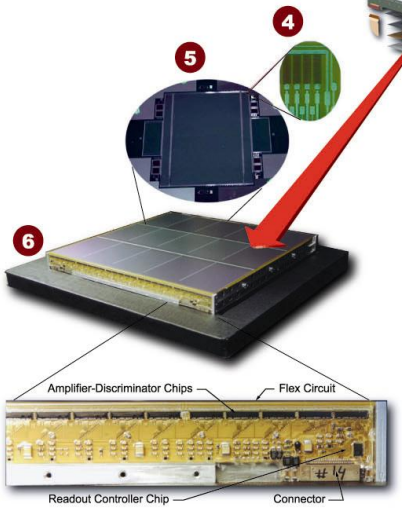
1. Tracker tower: stack of 19 trays with 18 x,y detection planes, enclosed in C walls.
2. Si strip detector cross section.
3. Exploded view of a tracker tray.
4. Si strips, bias resistors, and bonding pads.
5. 6" Si wafer, with a BTEM detector surrounded by test structures.
6. Complete tracker tray of the BTEM, with Si detectors on the top and bottom faces





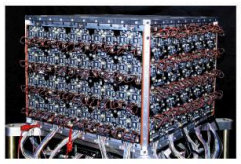


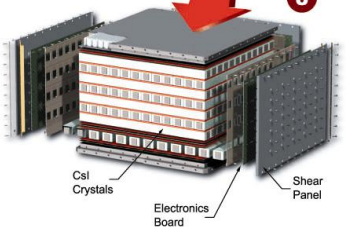


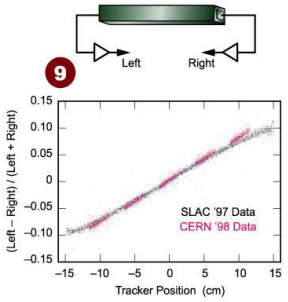


Calorimeter

7. Assembled BTEM CAL module.
8. CAL compression cell design
9. CAL beam-test results: Position measurement from left-right light asymmetry.





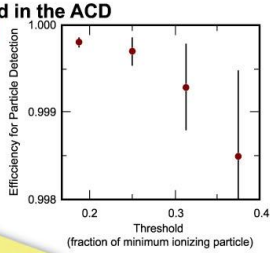


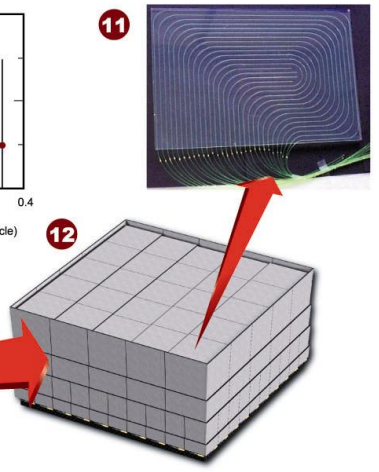
The Anticoincidence Shield

10. ACD beam-test results: efficiency to detect a minimum-ionizing particle versus the discriminator threshold. The required efficiency is 0.9997.

11. ACD scintillator tile, with waveshifting fiber readout.

12. The LAT enclosed in the ACD





GLAST Instrument

Key Features:
- Low Aspect Ratio—Wide Field of View
- Large Energy Reach, Excellent PSF
- Proven Detector Technologies
- Large Detector Performance Margins
- Modularity, Redundancy
- No Consumables

Instrument Detector Technologies

Tracker (TKR):
Silicon Microstrip Detectors
- High efficiency
- High signal/noise
- Robust, rad-hard, low voltage
- Widespread use in space and HEP

Calorimeter (CAL):
Cesium-Iodide crystals; PIN diode readout
- Excellent energy resolution over wide range
- High signal/noise
- Hodoscopic array gives good position resolution and shower leakage correction
- Widespread use in space and HEP

Anticoincidence Detectors (ACD):
Plastic scintillator tiles; waveshifting-fiber/PMT readout.

Systems work together to identify and measure the cosmic gamma ray flux with energy 0.02 to 300 GeV.

Large Area Telescope (LAT)

- **Precision Si-strip Tracker (TKR)**

  - Italy (ASI/INFN): provide Si-strip detectors & test all detectors, assemble & test detector trays, assemble & test TKR modules

  - Japan: provide Si-strip detectors & oversee detector production

  - SU-SLAC & UCSC (USA): provide Si-strip detectors, front-end electronics, cable plant

- **Hodoscopic CsI Calorimeter (CAL)**

  - IN2P3 (France): mechanical structure; CEA (France): engineering model prototypes of CDEs & test equipment;

  - Sweden: CsI xtals & acceptance testing;

  - NRL (USA): front-end electronics, provide photodiodes, assemble & test CDEs and CAL modules

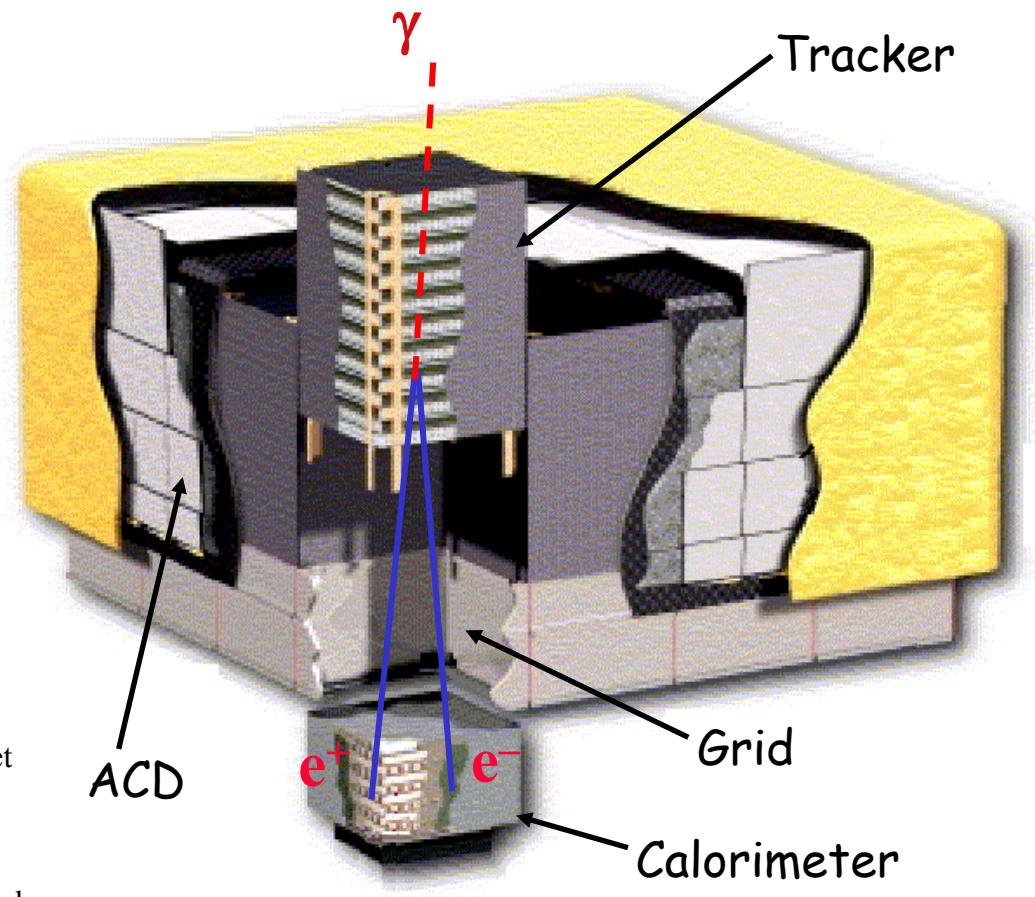
- **Segmented Anticoincidence Detector** including micrometeoriod shield / thermal blanket
  - GSFC (USA)

- **Electronics System**

  - SU-SLAC & NRL (USA): global electronics and DAQ equipment; flight software

- **Mechanical Thermal System**

  - SU-SLAC (USA): provide LAT Grid, thermal radiators, heat pipes & ancillaries



- **LAT I&T**

  - SU-SLAC (USA): assembly & test of LAT; provide particle/photon test beams

  - NRL (USA): instrument-level environmental tests

Richard Taylor
(Nov 2, 1929 – Feb 22, 2018)

Persis Drell
1st chair of Fermi IFC

establishing DOE – NASA partnership also critical to success

Steven Chu Burton Richter

GLAST is an International Mission

Leaning Tower

GLAST Tracker Tower

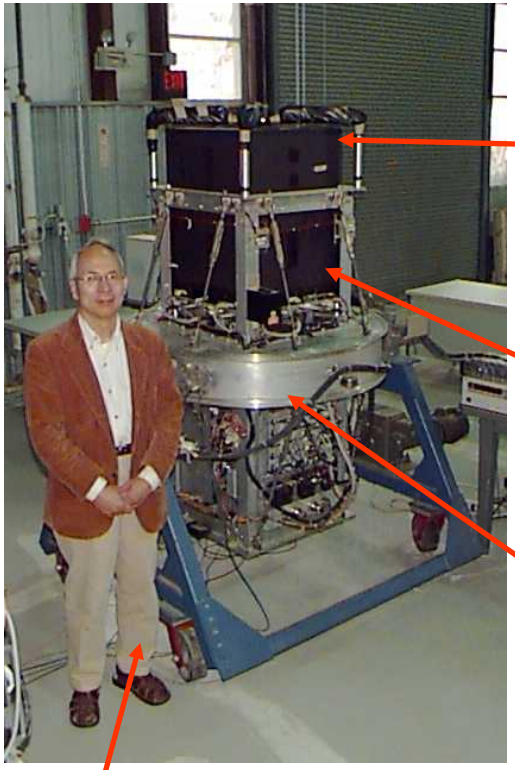
Ronaldo Bellazzini

Balloon Flight Test of GLAST LAT Module

Step 1: prove that the technology worked in a relevant environment – e.g. balloon flight of LAT engineering prototype module

Successful flight on August 4, 2001 from Palestine, Texas to location near Crawford, Texas

Balloon Flight Payload

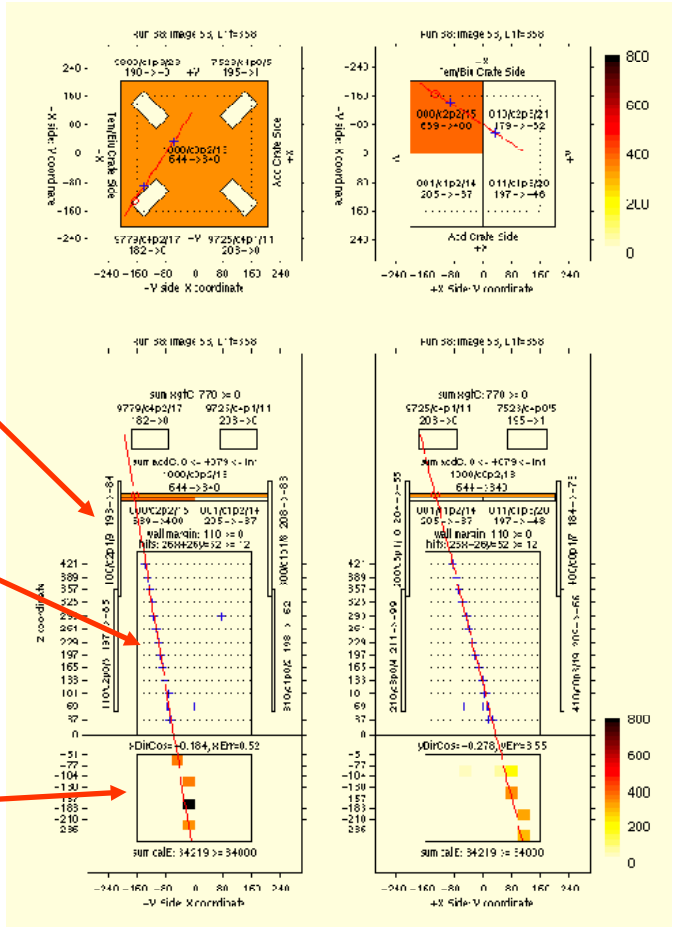


Anticoincidence Detector (ACD) Shield

Tracker Module (TKR)

Calorimeter Module (CAL)

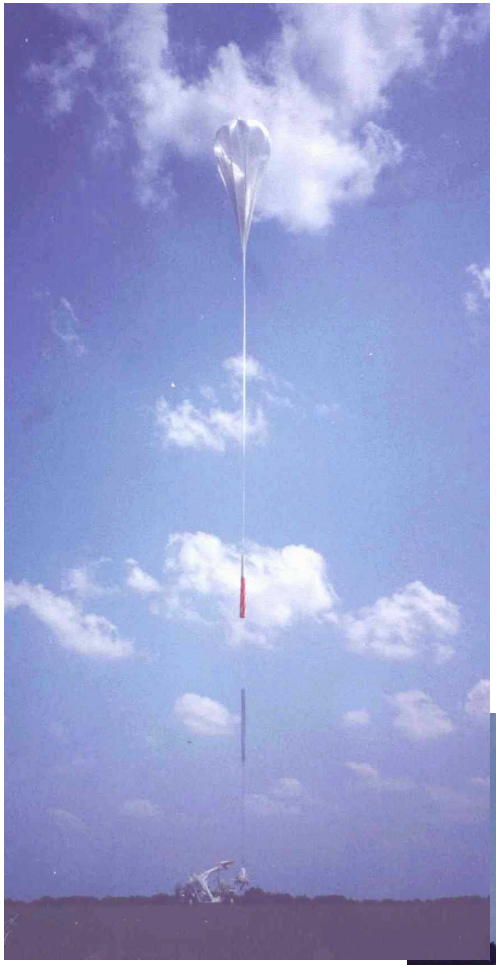
Instrument Technical Manager, Tuneyoshi Kamae (Tokyo/Stanford University/SLAC)



Real-time event display of a muon track

Balloon Flight Operations: NSBF, Palestine, Texas

Payload, inside of Pressure Vessel, mounted to GRIS Gondola



Successful launch of NSBF flight 1579-P on August 4, 2001

Balloon Flight Ops team at NSBF, Palestine, Texas

Balloon Flight Objectives

Purpose of balloon test flight: expose prototype LAT tower module to a charged particle environment similar to space environment and accomplish the following objectives:

a) Validate the basic LAT design at the single tower level.

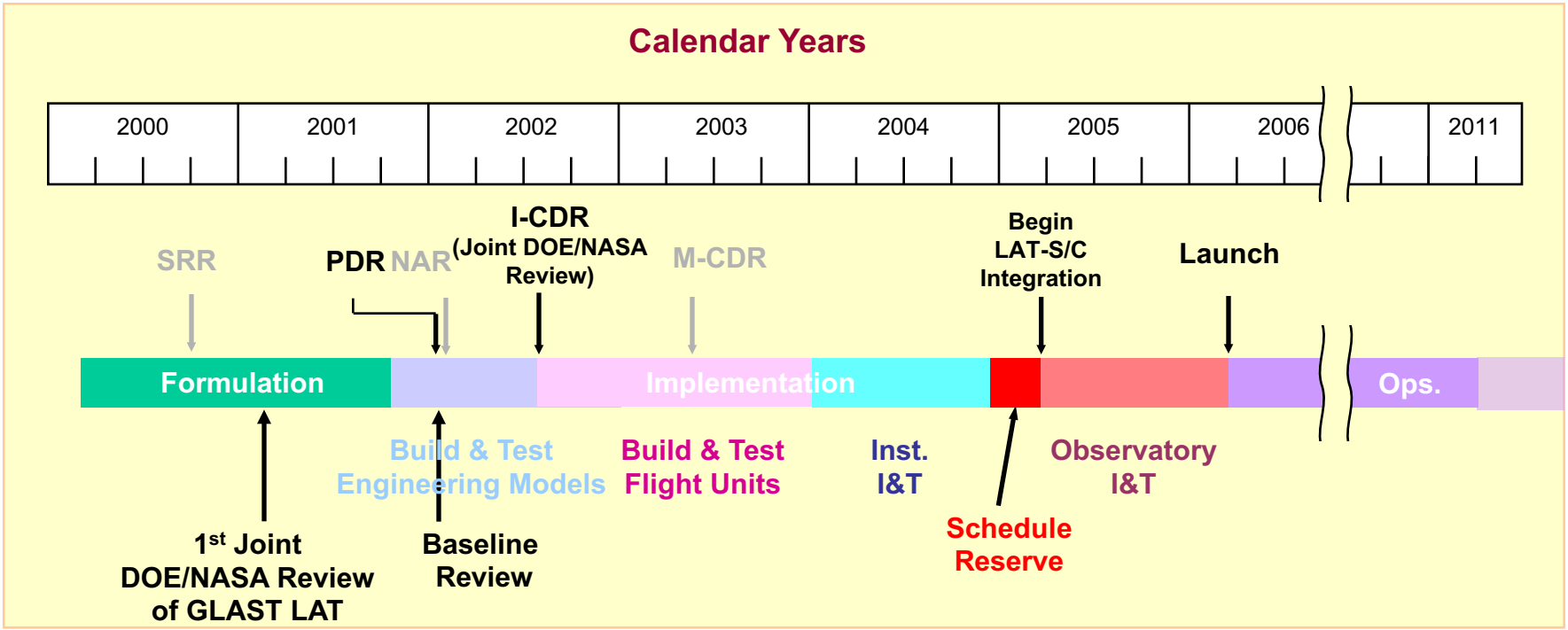
b) Show ability to take data in the high isotropic background flux of energetic particles in the balloon environment.

c) Recording all or partial particle incidences in an unbiased way that can be used as a background event data base.

d) Find an efficient data analysis chain that meet the requirement for the future Instrument Operation Center of GLAST.

All Objectives met by Balloon Flight on August 4, 2001

GLAST LAT Schedule



GLAST scheduled for launch in March 2006

Paul Hertz, NASA

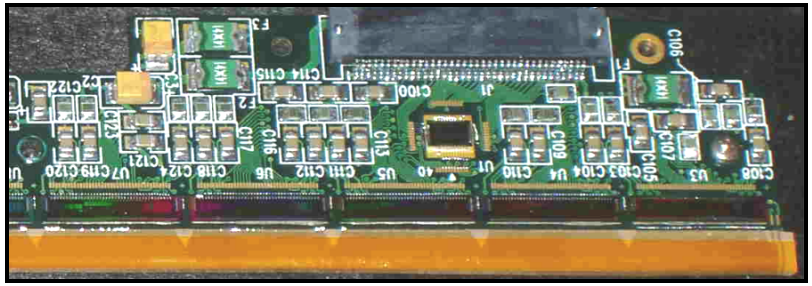
Kathy Turner, DOE

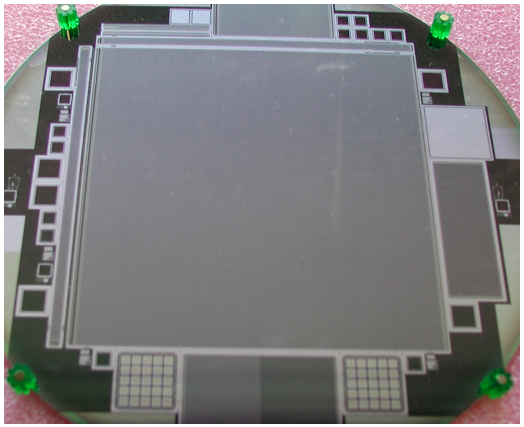
Peter Michelson, LAT PI

GLAST User's Committee meeting – August 2004

Flight Hardware Production

Tracker Multi-Chip Modules
(648; 204 produced; 16,848 ASICs)

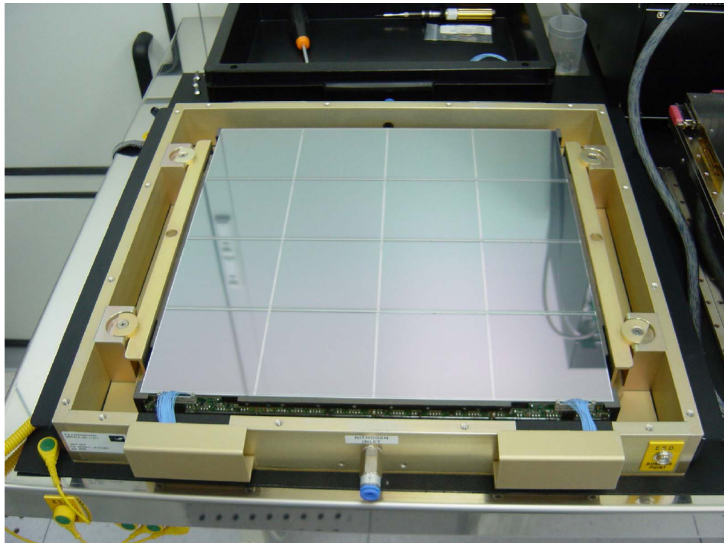


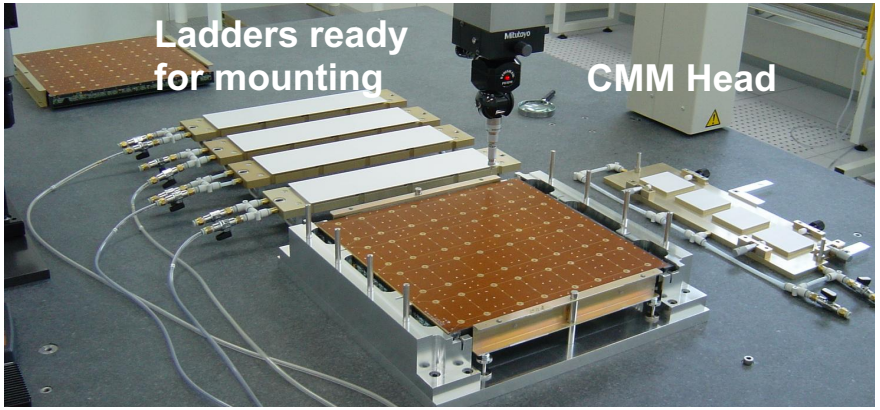


Silicon Strip Detectors

(10,368; 11,500 tested; 63 rejects)

Tray Assembly at G&A, Italy
(324; 2 completed)





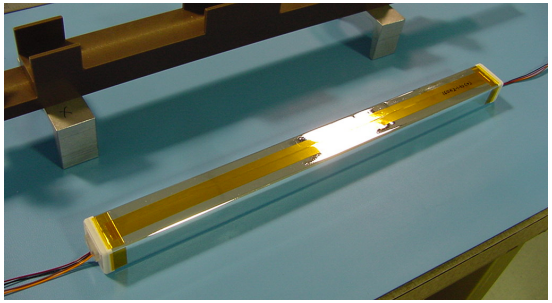
Silicon Detector Ladder production at G&A and Mipot, Italy

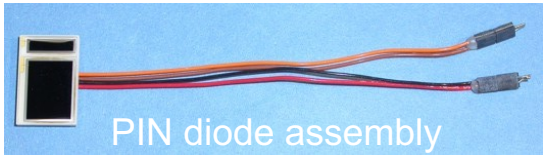
(2,592; 967 assembled & tested; 16 rejects)

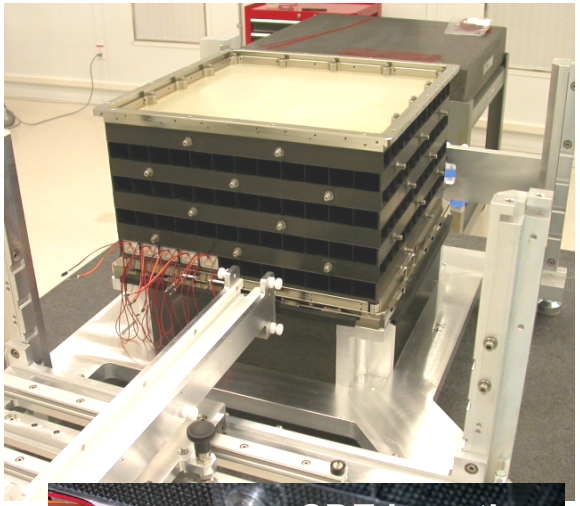
Calorimeter Flight Hardware Production

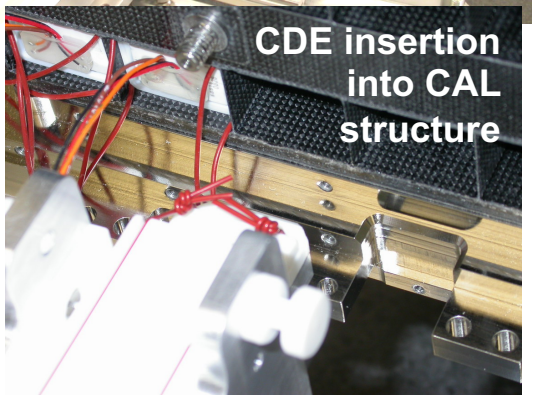
Calorimeter Crystal Detector (CDE) assembly at Swales Aerospace

(1,728, 1,534 completed)







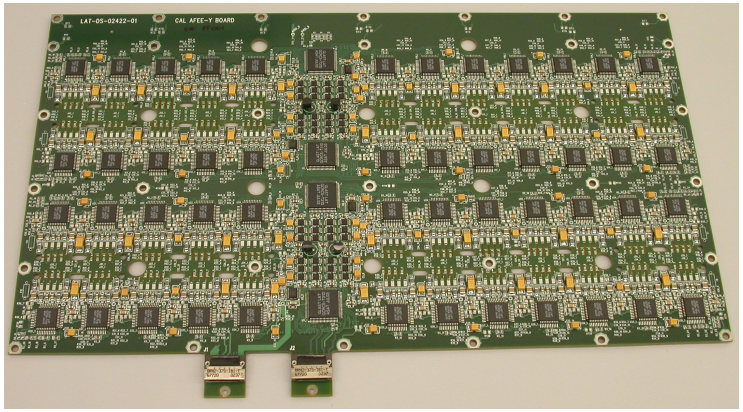


Assembly of 8 Flight PEMs (Pre-Electronics Modules) completed and tested (muons) at NRL

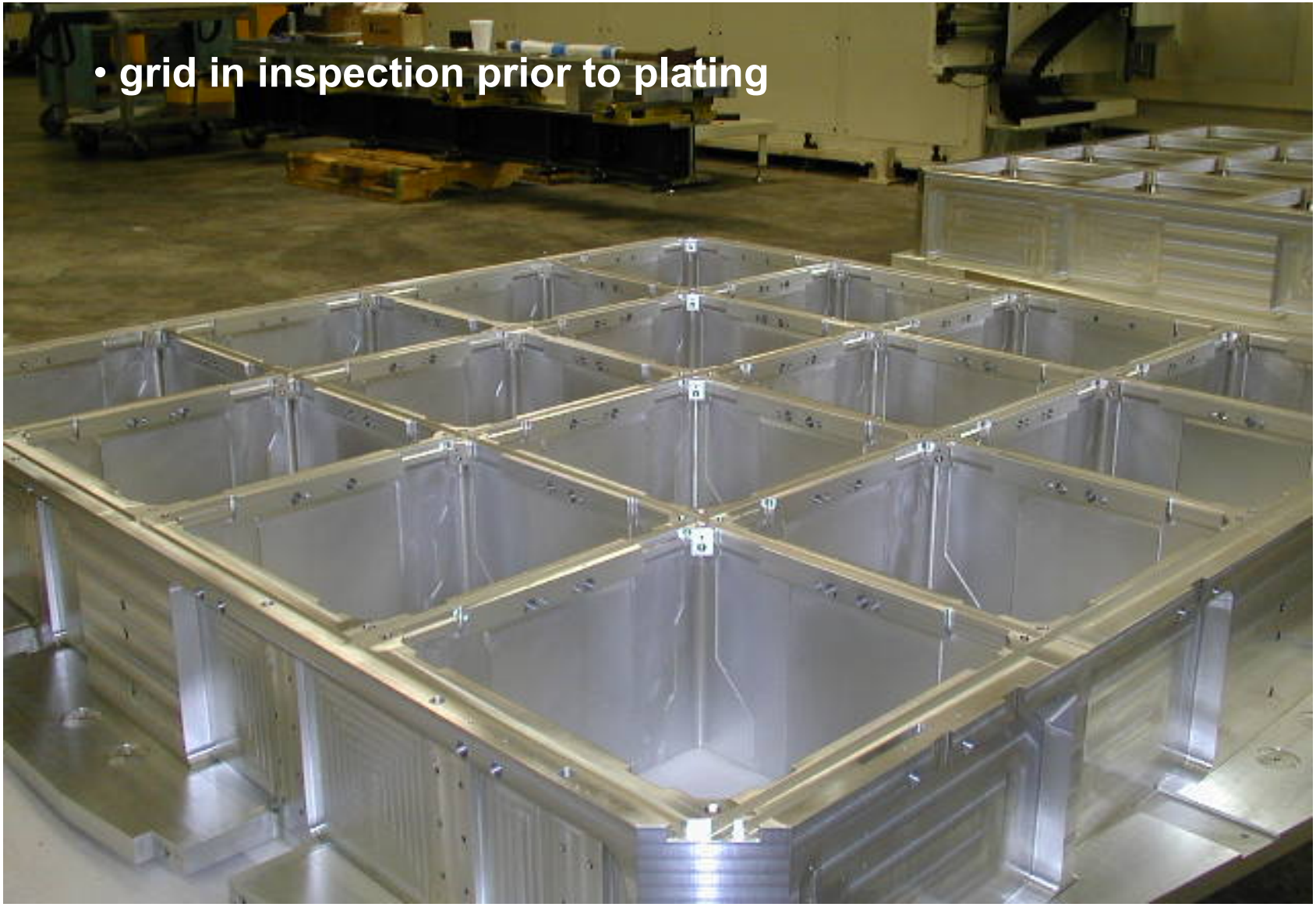
All Flight AFEE Cards (110) have been manufactured

but,

Novacap capacitors need to be replaced (done on 38 boards)



Grid machining completed



Data Acquisition Test Bed

Tracker ribbon cables were an unanticipated challenge

Descope discussion – 2005

Dr. Anne Kinney, NASA Astrophysics Division Director 2005

Volume 1 - Scientific and Technical Plan

Table 2.2.18: Science Impact of Descoping from 16 to 12 Towers

	A_{eff} Dependance	LAT Baseline	LAT Performance Floor	GLAST SRD	EGRET
A_{eff} at 1 GeV (cm^2)		11,400	8,600	8,000	1,600
Source Sensitivity (Photons cm^{-2} s^{-1})	$(A_{eff})^{-1/2}$	1.6×10^{-9}	1.8×10^{-9}	4.0×10^{-9}	5×10^{-8}
Time Study Variable Sources	A_{eff}	$0.13 \times T_{EGRET}$	$0.18 \times T_{EGRET}$		T_{EGRET}
Number of AGN	$A_{eff}^{0.65}$	10,900	9,800	4,500	80

Table 2.2.19: Impact of Descoping by Removal of LAT Towers

Action		Performance Loss	Risk	Science Impact	Resource Impact to NASA		
					Mass	Power	Cost
Omit 2 Calibration Towers		None	Moderate I&T	None	0	0	-$3.35M
Omit Flight Towers	2	12% of A_{eff}	No Additional	Decreased sensitivity at all energies	-263 kg	- 70 W	-$3.35M
	4	25% of A_{eff}			-526 kg	-140 W	-$6.70M


GLAST - February 2007 launch


Fermi at General Dynamics (Spectrum-Astro),
Gilbert, Arizona Fall 2007
G070336-024

Thermal Vac Testing at the Naval Research Laboratory, Fall 2007


Thermal Vac Testing at the Naval Research Laboratory, Fall 2007

2008
Fermi at Kennedy Space Center – preparation for launch


USAF
ULA
DELTA
GLAST
NASA


7
8
6


Pitch in!

GLAST launch: June 11, 2008
12:05 PM EST

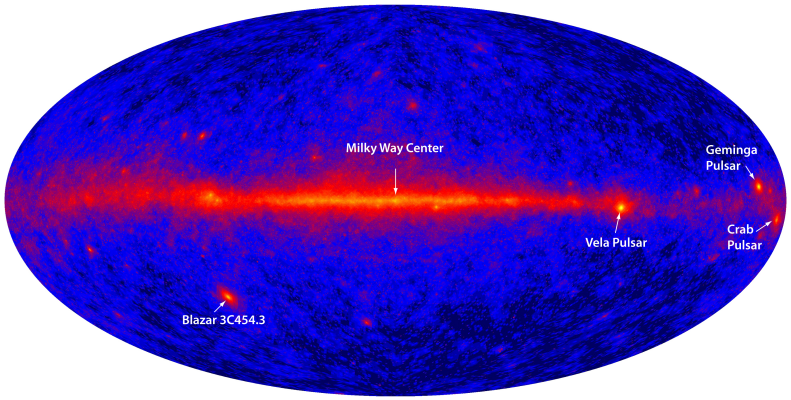
GLAST, renamed Fermi, reveals first all-sky image

August 26, 2008

WASHINGTON -- NASA's newest observatory, the Gamma-ray Large Area Space Telescope, or GLAST, has begun its mission of exploring the universe in high-energy gamma rays. The spacecraft and its revolutionary instruments passed their orbital checkout with flying colors.

NASA announced today that GLAST has been renamed the Fermi Gamma-ray Space Telescope. The new name honors Prof. Enrico Fermi (1901 - 1954), a pioneer in high-energy physics.."

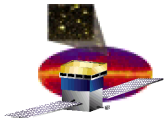
"Enrico Fermi was the first person to suggest how cosmic particles could be accelerated to high speeds," said Paul Hertz, chief scientist for NASA's Science Mission Directorate at NASA Headquarters in Washington. "His theory provides the foundation for understanding the new phenomena his namesake telescope will discover."



Gamma Rays: The Incredible, Hulking Reality

By Charles Q. Choi, Live Science Contributor | June 11, 2008 06:39am ET

Fermi LAT Collaboration meeting – SLAC 2009



lessons learned

- Successful international collaborations:
  - shared passion for science objectives
  - problems & challenges belong to everyone
  - successes belong to everyone

- Be optimistic: success takes longer than you think!

Table 2.2.5: Summary of the Tracker Technology Trade Study[a]

		Silicon-Strip Detectors		Scintillation Fibers/PMT readout
Detection Principle		Electron-hole creation from ionization in PIN diode.		Light production by scintillation in plastic fibers.
Readout		Direct VLSI Readout; simple, compact interface. 150 V max.		PMT, Amplifier. Bulky; large dead mass around Tracker; complex interface. High voltage.
# detected primaries	√	80,000 e^-,hole pairs/mm Highly efficient, robust.		5-15 photoelectrons/mm. Low efficiency; high risk from system degradation.
Efficiency/layer	√	>99% in active area.		60-90% in active area (see text).
Minimum Pitch	√	≈0.05 mm. Gives no restriction on capability for GLAST.		≈0.5 mm for MIP detection. Restricts attainable resolution at high energy.
Resolution	√	Predictable: ≤ strip pitch divided by root(12)		Existing HEP implementations have been limited by poor signal/noise and crosstalk.
Dead regions; Distribution	√	Edges of Si detectors. Localized.		Surrounding every fiber (cladding). Distributed over entire Tracker plane.
Ground experience with large system (see text)	√	Extensive. Virtually every modern HEP experiment. Excellent performance for MIPs.		Two relatively small experiments with Multi-Anode PMT readout. Marginal performance.
Space experience with large system	√	AMS experiment; sensitive to MIPs. Double sided, small pitch⇒much more complex than GLAST.		None with PMT readout, some with image-intensifier readout for heavy-ion detection.
Sensitivity of readout to MIPs	√	None.		Could be problematic for PMTs.
Channel Count		Large, due to small pitch and limited strip length.	√	Long fibers allow coverage of a large area with fewer channels.
Cost	√	Detectors now at an acceptable level for large systems.	√	Higher per channel; May be compensated by reduced channel count.
Power Consumption	√	Potentially large, due to large channel count. Addressed by low-power ASIC development	√	Higher per channel; May be compensated by reduced channel count.
Assembly	√	Standard industrial large-scale, precision assembly techniques. Strips within detectors are naturally extremely precise.		Precision assembly and alignment of thousands of individual long fibers. Calibration of misalignments of individual fibers would be very difficult or impossible to implement.
Calibration	√	Insensitive. Small threshold dispersion. Highly stable.		Efficiency is highly sensitive to calibration of each PMT anode. Questionable stability.
Modularity	√	Required by strip length. Helps track reconstruction, redundancy, and I&T.		Long fibers allow construction in single module. Yields favorable channel count but larger pattern ambiguities in complex events.

a. We chose silicon-strip detectors because of their high performance and robust operation (low performance risk).