National Aeronautics Space Administration

GLAST SCIENCE WRITER'S GUIDE

"Exploring the Extreme Universe"

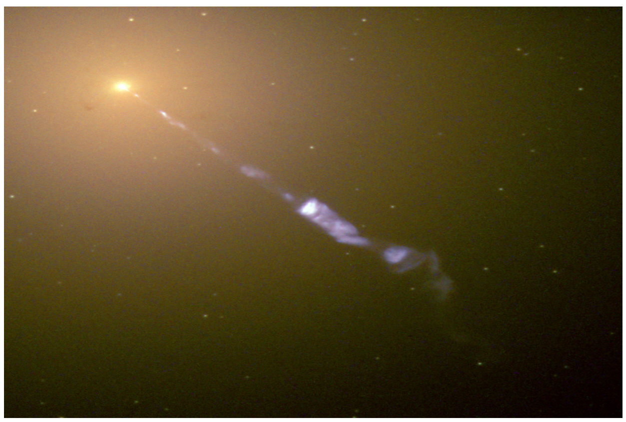
Credit: NASA E/PO, Sonoma State University, Aurore Simonnet

A guide for reporters to understand the mission and purpose of the
GAMMA-RAY LARGE AREA SPACE TELESCOPE
(GLAST)
A NASA mission in collaboration with the U.S. Department of Energy
and many domestic and international partners

September 2007 Draft

NASA's Gamma-ray Large Area Space Telescope (GLAST) is a powerful space observatory that will:

1. Explore the Universe's ultimate frontier, where nature harnesses forces and energies far beyond anything possible on Earth.
2. Probe some of science's deepest questions, such as what our Universe is made of, and search for new laws of physics.
3. Explain how black holes accelerate jets of material to nearly light speed.
4. Help crack the mystery of stupendously powerful explosions known as gamma-ray bursts.
5. Answer long-standing questions across a broad range of topics, including solar flares, pulsars, and the origin of cosmic rays.



Black hole-powered jet of electrons and other subatomic particles stream from the center of Galaxy M87 Credit: NASA and The Hubble Heritage Team (STScI/AURA)

CREDITS

Lead Editors/Layout:
Lynn Cominsky, Sonoma State University, Calif.
Rob Gutro, NASA Goddard Space Flight Center (GSFC)
Robert Naeye, NASA GSFC
Layout Designer: Ruth Jennings, NASA GSFC

Contributing Authors and Editors:
J.D. (Dan) Blackwood, NASA Headquarters (HQ)
Neil Calder, U.S. Dept. of Energy (DOE), Stanford Linear Accelerator Center
Neil Gehrels, NASA GSFC
Kevin Grady, NASA GSFC
Mike Greenwood, General Dynamics, AIS
F. Rick Harnden, Jr., NASA HQ
Grey Hautaluoma, NASA HQ
Julie McEnery, NASA GSFC
Charles "Chip" Meegan, Marshall Space Flight Center
Peter Michelson, Stanford University
Steve Ritz, NASA GSFC
Mark Seidleck, NASA GSFC
David Thompson, NASA GSFC
Kathy Turner, U.S. DOE
Marcus Woo, Freelance Science Writer

GLAST, NASA's new gamma-ray observatory, will open a wide window on the universe. Gamma rays are the highest-energy form of light and the gamma-ray sky is spectacularly different from the one we perceive with our own eyes. With a huge leap in all key capabilities, GLAST data will enable scientists to answer persistent questions across a broad range of topics, including supermassive black-hole systems, pulsars, the origin of cosmic rays, and searches for signals of new physics.

NASA's GLAST mission is an astrophysics and particle physics partnership, developed in collaboration with the U.S. Department of Energy, along with important contributions from academic institutions and partners in France, Germany, Italy, Japan, Sweden, and the U.S.

NASA
Science Mission Directorate

GLAST
(Gamma-ray Large Area Space Telescope)
SCIENCE WRITER'S GUIDE

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Steve Ritz
NASA Goddard Space Flight Center
Steve.Ritz@nasa.gov
Tel. 301-286-0941

GLAST LARGE AREA TELESCOPE (LAT) PRINCIPAL INVESTIGATOR:
Peter Michelson
Stanford University
peterm@stanford.edu
Tel. 650-723-3004

GLAST BURST MONITOR (GBM) PRINCIPAL INVESTIGATOR:
Charles “Chip” Meegan
NASA Marshall Space Flight Center
chip.meegan@nasa.gov
Tel. 256-961-7694

GLAST DEPUTY PROJECT SCIENTIST:
Neil Gehrels
NASA Goddard Space Flight Center
Neil.Gehrels@nasa.gov
Tel. 301-286-6546

GLAST DEPUTY PROJECT SCIENTIST:
Julie McEnery
NASA Goddard Space Flight Center
Julie.E.McEnery@nasa.gov
Tel. 301-286-1632

GLAST RELATED PUBLICATIONS

- GLAST Brochure: http://glast.sonoma.edu/resources/brochure/glastbroch04.pdf
- GLAST Fact Sheets:
  http://glast.gsfc.nasa.gov/public/resources/pubs/factsheet/Sci_Fact_Sheet.pdf
- http://www.fisica.uniud.it/~glast/docs/a06518glastfa1.pdf

PUBLIC AFFAIRS CONTACTS:

NASA Headquarters
Grey Hautaluoma
202-358-0668
Grey.hautaluoma-1@nasa.gov

Goddard Space Flight Center
Rob Gutro
301-286-4044
Robert.J.Gutro@nasa.gov

Marshall Space Flight Center
Jennifer Morcone
256-544-7199
Jennifer.J.Morcone@nasa.gov

NASA-TV
Liz Smith
Television Producer
301-286-1540
Liz.Smith@nasa.gov

Sonoma State University
Lynn Cominsky
GLAST Press Officer
707-664-2655
lynnc@universe.sonoma.edu

U.S. Dept. of Energy, SLAC
Neil Calder
650-926-8707
neil.calder@slac.stanford.edu

Stanford University
John Sanford
650-714-3000
jsanford@stanford.edu

U.S. Dept of Energy
Peter Lincoln
202-586-9010
peter.lincoln@science.doe.gov

Goddard Space Flight Center
Robert Naeye
301-286-4453
Robert.P.Naeye@nasa.gov

GLAST RELATED WEB SITES

MAIN NASA GLAST WEB SITE: http://www.nasa.gov/glast
NASA GLAST MISSION WEB SITE: http://glast.gsfc.nasa.gov
EDUCATION WEB SITE SONOMA STATE UNIVERSITY: http://glast.sonoma.edu
GLAST Multimedia Gallery: http://glast.sonoma.edu/resources

MAIN GLAST INSTRUMENT WEB SITES:

LAT instrument at Stanford University: http://glast.stanford.edu/
GBM instrument at Marshall Space Flight Center: http://www.batse.msfc.nasa.gov/gbm/

GLAST is NASA’s next-generation mission designed to explore the most energetic phenomena in our Universe.

GLAST KEY SCIENTIFIC OBJECTIVES

NASA's Gamma-ray Large Area Space Telescope (GLAST) is a powerful space observatory that will:

1. Explore the Universe's ultimate frontier, where nature harnesses forces and energies far beyond anything possible on Earth.
2. Probe some of science's deepest questions, such as what our Universe is made of, and search for new laws of physics.
3. Explain how black holes accelerate jets of material to nearly light speed.
4. Help crack the mystery of stupendously powerful explosions known as gamma-ray bursts.
5. Answer long-standing questions across a broad range of topics, including solar flares, pulsars, and the origin of cosmic rays.

Q&A ON THE GLAST MISSION

MISSION FACTS / SCIENCE:

WHAT DOES "GLAST" STAND FOR? Gamma-ray Large Area Space Telescope

WHAT IS THE PURPOSE OF THE GLAST MISSION?
The Universe is home to numerous exotic and beautiful phenomena, some of which can generate inconceivable amounts of energy. GLAST will open this high-energy world. Astronomers will have a superior tool to study how black holes, notorious for pulling matter in, can accelerate jets of gas outward at fantastic speeds. Physicists will be able to search for signals of new fundamental processes that are inaccessible in ground-based accelerators and observatories.

WHAT ARE GLAST'S MAIN MISSION OBJECTIVES?
- To understand the mechanisms of particle acceleration in active galactic nuclei (AGNs), neutron stars, and supernova remnants (SNRs).
- Resolve the gamma-ray sky: characterize unidentified sources and diffuse emission.
- Determine the high-energy behavior of gamma-ray bursts (GRBs) and variable sources.
- Probe dark matter and the early Universe.

WHAT KINDS OF THINGS WILL GLAST STUDY? (See Features section of this guide)
1. Blazars and Active Galaxies
2. Gamma-ray Bursts
3. Neutron Stars
4. Cosmic Rays and Supernova Remnants
5. Milky Way Galaxy
6. The Gamma-ray Background
7. The Early Universe
8. Solar System: Sun, Moon, and Earth
9. Dark Matter
10. Testing Fundamental Physics
11. Unidentified Sources and the Unknown

WHAT'S NEW AND REVOLUTIONARY ABOUT THIS MISSION?
GLAST is the first imaging gamma-ray observatory to survey the entire sky every day and with high sensitivity. It will give scientists a unique opportunity to learn about the ever-changing Universe at extreme energies. GLAST will detect thousands of gamma-ray sources, most of which will be supermassive black holes in the cores of distant galaxies. GLAST uses Einstein's

principle of $E = mc^2$ to convert gamma rays into matter in order to track their cosmic origins. GLAST observations may reveal signatures of new physics, including the potential to identify the unknown particle which may compose dark matter.

WHAT ARE SOME OF THE QUESTIONS GLAST HOPES TO ANSWER?
How do black holes accelerate jets of material to nearly light speed? What is the mysterious dark matter? What mechanism produces the stupendously powerful explosions known as gamma-ray bursts? How do solar flares generate high-energy particles? How do pulsars work? What is the origin of cosmic rays? What else out there is shining gamma rays?

WHAT ARE GAMMA RAYS?
Gamma rays are the highest-energy forms of light in the electromagnetic spectrum. For more details, see the feature article on page 38.

WHAT PREVIOUS MISSIONS DOES GLAST CONTINUE AND IMPROVE UPON?
GLAST follows in the footsteps of NASA's Compton Gamma-ray Observatory (CGRO) EGRET and BATSE instruments, which were operational between 1991 and 1999. GLAST will have a field of view and sky survey twice as large as that of the CGRO, and a sensitivity more than 30 times greater than Compton's EGRET instrument. GLAST will also improve upon the BATSE instrument.

WHAT'S THE DIFFERENCE BETWEEN THE SWIFT AND GLAST SATELLITES?
Both missions look at gamma-ray bursts (GRBs), but in different ways. Swift can rapidly and precisely determine the locations of GRBs and observe their afterglows at X-ray, ultraviolet, and optical wavelengths. GLAST will provide exquisite observations of the burst over the gamma-ray spectrum, giving scientists their first complete view of the total energy released in these extraordinary events. Beyond GRB science, GLAST is a multipurpose observatory that will study a broad range of cosmic phenomena. Swift is also a multipurpose observatory, but was built primarily to study GRBs.

HOW BIG IS THE SPACECRAFT?
It is 9.2 feet (2.8 meters) high by 8.2 feet (2.5 meters) in diameter when stowed, where it is just under the 9-foot diameter allowed in the fairing. GLAST becomes a little bit taller and much wider after it is launched into space, when the Ku-band antenna deploys and the solar arrays are extended.

HOW LONG WILL THE MISSION LAST?
GLAST is expected to operate for a minimum of five years, but has a goal to operate 10 years.

WHERE WILL DATA ANALYSIS HAPPEN?
Around the world. Data analysis will be supported by GLAST's international science team and by the mission's science center, located at NASA's Goddard Space Flight Center (GSFC). The LAT Instrument Science Operations Center (ISOC) is located at Stanford Linear Accelerator Center, Menlo Park, Calif. The (GBM) Instrument Operations Center is located at the National Space Science and Technology Center (NSSTC) in Huntsville, Ala.

WHAT DOES GLAST MEAN TO THE AVERAGE PERSON?
The Universe looks remarkably different outside the narrow range of colors we can see with our eyes. GLAST's spectacular high-energy gamma-ray "eyeglasses" will reveal hidden wonders, opening our minds to new possibilities and discoveries, expanding our understanding of the Universe and our place in it. These new perspectives help us to think differently as well as inspire new generations of students.

GLAST WILL STUDY THE ORIGIN OF COSMIC RAYS. HOW DO COSMIC RAYS AFFECT US?

Although you may never yourself be bombarded by a primary cosmic ray (we are shielded from them by Earth's atmosphere), we are bombarded all the time by the secondary cascades of particles that are created when cosmic rays interact with Earth's atmosphere. These secondary particles are not as energetic, but they provide a constant background radiation to which we are all constantly exposed. Spacecraft and high-altitude planes certainly feel their effects. With the high energy of primary cosmic rays concentrated in such a small bundle, they can disrupt computer hardware or sensitive electronics and these instruments have to be shielded in vehicles traveling above the atmosphere.

WHAT DOES GLAST COST TO DESIGN, BUILD AND LAUNCH?

U.S. contribution $600 million; international contribution $90 million; Total $690 million.

WHERE IS GLAST'S ORBIT AND WHY IS GLAST IN THIS ORBIT?

Although gamma rays can travel across the Universe to give us their information, they cannot penetrate even the thinnest part of Earth's upper atmosphere. Therefore the detectors need to be placed above the atmosphere. To accomplish this, GLAST will be launched into circular orbit around Earth at an altitude of about 560 km (350 miles). This is a low-Earth orbit. This orbit is chosen to minimize the effects of charged particles that surround Earth, and which would create additional unwanted background signals in the detectors, while still ensuring the full mission lifetime. At that altitude, the observatory will circle Earth every 90 minutes. In sky-survey mode, GLAST will be able to view the entire sky in just two orbits, or about 3 hours.

WHAT DO PROJECT SCIENTISTS DO?

The primary role of the Project Scientist is to provide the scientific leadership necessary to assure that the mission implementation will meet or exceed the scientific requirements. The Project Scientist and her/his deputies are integral members of the Project management team. To accomplish these goals, the Project Scientist functions include: providing scientific oversight of all elements of the mission, reviewing and recommending approval or disapproval of proposed modifications to the science requirements or to the instruments, acting as the primary science interface between the science community and the project, and assuring public dissemination of scientific results through professional groups, peer reviewed publications, conferences, workshops, and the relevant public-affairs offices.

INSTRUMENTS:

WHAT ARE THE NAMES OF THE GLAST INSTRUMENTS?

1) Large Area Telescope (LAT)
2) GLAST Burst Monitor (GBM)

WHAT DOES THE LARGE AREA TELESCOPE (LAT) DO AND HOW DOES IT WORK?

The LAT detects gamma rays by using Einstein's famous $E = mc^2$ equation in a technique known as pair production. When a gamma ray, which is pure energy, slams into a layer of tungsten in the detector, it can create a pair of subatomic particles (an electron and its antimatter counterpart, a positron). The direction of the incoming gamma ray is determined by projecting the direction of these particles back to their source using several layers of high-precision silicon tracking detectors. A separate detector, called a calorimeter, absorbs and measures the energy of the particles. Since the energy of the particles created depends on the energy of the original gamma ray, counting up the total energy determines the energy of that gamma ray. Because the LAT in orbit is bombarded by many more particles than gamma rays, it wears a "hat" – a third detector that produces a signal when a particle, but not a gamma ray, goes through it. The combination of no signal in this outer detector ("the dog that did not bark"), plus an electron-positron pair of tracks created inside the LAT, signals a gamma ray. Working one gamma ray at a time, the LAT will make gamma-ray images of astronomical objects, while also determining the energy for each detected gamma ray. For more detail on the LAT, see page 34.

WHO HELPED CREATE THE LAT?
The U.S. Department of Energy (DOE) and NASA partnered on the building of the Large Area Telescope (LAT), the primary instrument on GLAST. There were major contributions from France, Italy, Japan, and Sweden. The laboratory that managed the construction of the LAT is the Stanford Linear Accelerator Center, a DOE-funded lab, located at and managed by Stanford University. Although the LAT is the work of literally hundreds of scientists, engineers, and technicians, the individual who contributed the most to the original design is Bill Atwood, now at the University of California, Santa Cruz.

One of the Large Area Telescope towers, which is composed of a stack of interleaved planes of silicon strips and tungsten converters. The LAT has 16 of these towers in a 4x4 array.
Credit: NASA

WHERE WAS THE LAT TESTED?
The LAT was tested extensively during the summer of 2006 at the U.S. Naval Research Laboratory in Washington, D.C. LAT hardware was also used in beam tests at the European Center for Nuclear Research (CERN) and the German Heavy Ion Facility (GSI). The LAT was shipped to the General Dynamics facility in Arizona for integration onto the spacecraft bus. The General Dynamics spacecraft bus provides the power, data, and pointing resources that will enable the LAT to perform its survey of the Universe. Subsequent to the mechanical integration, the command, data, and power interfaces between the instrument and the spacecraft were tested rigorously to insure the compatibility of this spaceflight hardware that had been manufactured all around the globe.

WHAT DOES THE GLAST BURST MONITOR (GBM) DO?
The GLAST Burst Monitor (GBM) was selected as a complementary instrument for the GLAST mission and will be sensitive to X rays and gamma rays with energies between 8 keV and 30 MeV.

WHO HELPED CREATE THE GBM?
The development of the GLAST Burst Monitor and analysis of its observational data is a collaborative effort between the National Space Science and Technology Center in the U.S. and the Max Planck Institute for Extraterrestrial Physics (MPE) in Germany.

HOW WILL THE INSTRUMENTS WORK TOGETHER?
The GBM has an even larger field of view than the LAT. The GBM can see all directions at once, except for the area where Earth blocks its view. When the GBM detects a bright gamma-ray burst, it immediately sends a signal to the LAT to observe that area of the sky. It will do this if it is not already in the field of view, and if it is permissible to move there due to logistical constraints.

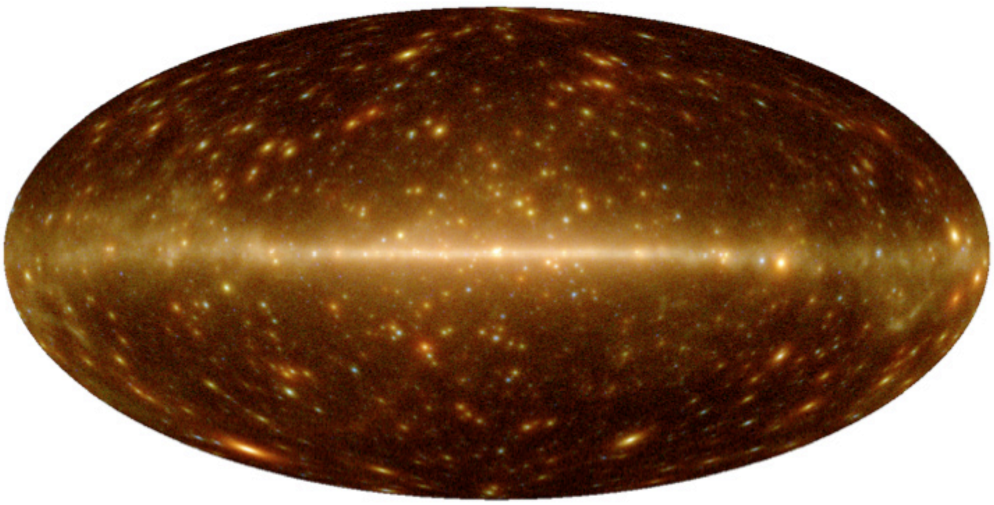
WHAT'S A "GEE-WHIZ FACT" ABOUT THE TECHNOLOGY?
The LAT is a 3-ton detector with almost a million channels of electronics, but it uses less than half the power of an ordinary hair dryer.

LAUNCH / DATA:

WHERE AND WHEN IS THE LAUNCH SCHEDULED?
The launch is scheduled for early 2008 from Cape Canaveral Air Station, on Florida's east coast. GLAST will be carried on a Delta II Heavy launch vehicle, with 9 solid rocket boosters. The solids are actually from the Delta III series (hence the term "heavy"), mounted on a Delta II. It has a 10 foot fairing and two stages.

WHEN ARE THE FIRST RESULTS EXPECTED?
The observatory is activated and tested in the first 60 days after launch. Basic “first light” results may come by day 90.

WHAT WILL THE GLAST IMAGES LOOK LIKE?
GLAST images will typically be intensity gamma-ray maps, often with different colors representing different energy ranges. These maps will be either a small number of individual sources, or as much as the entire sky. There will also be information about energy spectra and timing in some cases. An example of a simulated GLAST sky is shown below.



Simulated GLAST Sky after one year of operation.
Credit: LAT Team

HOW WILL THE DATA BE DISTRIBUTED?
The data will be made available over the Internet from the GLAST Science Support Center (GSSC) at NASA’s Goddard Space Flight Center.

HOW AND WHERE WILL THE DATA BE PROCESSED?
Data analysis will be performed at two remote science centers, located at the Stanford Linear Accelerator Center, operated by Stanford University for the U.S. Dept. of Energy, and at NASA’s Marshall Space Flight Center, in Huntsville, Alabama. GLAST data goes to the GSSC and is then distributed to the science community.

WHERE WILL MISSION OPERATIONS BE?
Mission operations will be performed from facilities at NASA’s Goddard Space Flight Center.

WILL THE GLAST MISSION BE RENAMED AFTER LAUNCH?
Yes. GLAST will receive a new name once it is in orbit.

WHO CAN HELP WITH PRESS RELEASES, INTERVIEWS, OTHER RESOURCES? VIDEO?
NASA and Sonoma State public-affairs officers can provide the latest press releases, breaking news, video, and arrange interviews. At Sonoma State University, contact Lynn Cominsky, Education and Public Outreach, Tel. 707-664-2655, email: lynnc@universe.sonoma.edu.

At NASA's Goddard Space Flight Center, contact: Rob Gutro, Public Affairs Officer, Tel. 301-286-4044 or by email Robert.J.Gutro@nasa.gov or Robert Naeye, Science Writer, Tel. 301-286-4453, Robert.P.Naeye@nasa.gov. Video and animation requests should be directed to Liz Smith at NASA-TV. Tel. 301-286-1540, Liz.Smith@nasa.gov.

WHO CAN HELP WITH LAUNCH SUPPORT IN PUBLIC AFFAIRS?
George Diller will provide public-affairs launch support from Kennedy Space Center, Fla. Tel. 321-861-7643 Email: george.h.diller@nasa.gov. The GLAST launch will occur from Cape Canaveral Air Station, adjacent to the Kennedy Space Center.

PARTNERS:

WHO ARE THE PARTNERS INVOLVED WITH THE MISSION?
NASA's GLAST mission is an astrophysics and particle-physics partnership, developed in collaboration with the U.S. Department of Energy, along with important contributions from academic institutions and partners in France, Germany, Italy, Japan, Sweden, and the U.S.

PARTNERS ON GLAST HARDWARE INCLUDE:

- **French Institutions**
  - Centre d'Études nucléaires de Bordeaux Gradignan (IN2P3/CENBG)
  - Commissariat à l'Energie Atomique, Département d'Astrophysique (CEA/DAPNIA), de physique des Particules, de physique Nucléaire et de l'Instrumentation Associée, CEA, Saclay
  - Institut National de Physique Nucléaire et de Physique des Particules, IN2P3
  - Laboratoire de Physique Théorique et Astroparticules, Montpellier, GAM (IN2P3/LPTA)
  - Laboratoire Leprince-Ringuet de l'École Polytechnique (IN2P3/LLR)

- **German Institution**
  - Max Planck Institute for Extraterrestrial Physics

- **Italian Institutions**
  - Instituto Nazionale di Fisica Nucleare
  - Italian Space Agency (ASI)
  - Istituto di Fisica Cosmica, Milano, CNR
  - INFN and University of Bari
  - INFN and University of Padova
  - INFN and University of Perugia
  - INFN and University of Pisa
  - INFN and University of Rome 2
  - INFN and University of Trieste
  - INFN and University of Udine

- **Japanese Institutions**
  - University of Tokyo
  - Tokyo Institute of Technology
  - Institute for Cosmic-Ray Research (ICRR)
  - Institute for Space and Astronautical Science (ISAS)
  - Hiroshima University

- **Swedish Institutions**
  - Royal Institute of Technology (KTH)
  - Stockholms Universitet

- **U.S. Institutions**
  - Los Alamos National Laboratory
  - NASA's Goddard Space Flight Center, Astrophysics Science Division

NASA's Marshall Space Flight Center
Ohio State University, Physics Department
Sonoma State University, NASA's Education and Public Outreach Group
Stanford University (SU), Physics Department
Stanford University, Hansen Experimental Physics Laboratory (HEPL) and Kavli Institute for Particle Astrophysics and Cosmology (KIPAC)
Stanford University, Stanford Linear Accelerator Center (SLAC)
Texas A&M University-Kingsville
University of Alabama in Huntsville
University of California at Santa Cruz, Physics Department & SCIPP
University of Washington
U.S. Department of Energy
U.S. Naval Research Laboratory, High Energy Space Environment (HESE) branch

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE FRENCH PARTNERS?
They designed and built the support structure for the LAT Calorimeter.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE GERMAN PARTNER?
The Max Planck Institute built all of the sensors and the power-supply box and support on the GLAST Burst Monitor (GBM) instrument. One of its scientists is the GBM Co-principal Investigator.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE ITALIAN PARTNERS?
They provided particle physics and astrophysics expertise and physically built the LAT Tracker.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE JAPANESE PARTNERS?
They provided oversight in the making of the silicon-strip detectors in the LAT Tracker.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE SWEDISH PARTNERS?
They provided sensors for the LAT Calorimeter.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF NASA's GODDARD SPACE FLIGHT CENTER?
NASA Goddard managed and built the LAT Anticoincidence Detector (ACD). The overall GLAST Program Mission Management and Mission Systems Engineering are provided by NASA Goddard. In addition, the Mission Operations Center (MOC) and the GLAST Science Support Center (GSSC) were provided by and are located at NASA Goddard.

WHAT WERE THE CONTRIBUTIONS OF NASA's KENNEDY SPACE CENTER?
NASA's Launch Services Program office at the Kennedy Space Center (KSC) is responsible for countdown management of the Delta II rocket for GLAST. KSC is also responsible for the integration of GLAST with the Delta II, provides ground support necessary for final GLAST spacecraft preparations. The Delta II is provided to NASA as a launch service by the United Launch Alliance. The spacecraft will launch from Space Launch Complex 17 at Cape Canaveral Air Force Station.

WHAT WERE THE CONTRIBUTIONS OF NASA's MARSHALL SPACE FLIGHT CENTER?
It provided the Data Processing Unit and instrument integration and testing. The management of the GLAST Burst Monitor (GBM) instrument is done through the National Space Science and Technical Center, out of NASA Marshall, Huntsville, Ala. Charles Meegan is the GBM Principal Investigator.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE NAVAL RESEARCH LABORATORY?
It managed the building of the LAT Calorimeter.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF THE OHIO STATE UNIVERSITY?
It provided particle physicists, and helped with trigger and data systems, including the algorithms on-board.

WHAT WERE THE CONTRIBUTIONS OF SONOMA STATE UNIVERSITY?
It provides management of education and public outreach.

WHAT WERE THE HARDWARE CONTRIBUTIONS OF STANFORD UNIVERSITY?
It is the lead on the Large Area Telescope (LAT). Peter Michelson is the LAT Principal Investigator. Stanford managed the LAT and hosts the Instrument Science Operations Center (ISOC) at the Stanford Linear Accelerator Center. The ISOC is where all the raw data from the LAT is processed and made ready for scientific analysis. The data is sent to the GLAST Science Support Center at NASA GSFC from where it is distributed to the scientific community.

WHAT WERE THE CONTRIBUTIONS OF THE UNIVERSITY OF CALIFORNIA, SANTA CRUZ?
It provided management of the Tracker in the LAT.

WHAT WERE THE CONTRIBUTIONS OF THE UNIVERSITY OF WASHINGTON?
It provided software support.

WHAT WERE THE U.S. DEPARTMENT OF ENERGY'S (DOE) AND SLAC'S HARDWARE CONTRIBUTIONS?
The Large Area Telescope (LAT) is managed at the U.S. DOE Stanford Linear Accelerator Center (SLAC), a U.S. DOE lab. SLAC was responsible for the overall design and development of the LAT.

WHO IS RESPONSIBLE FOR BUILDING THE ACTUAL SPACECRAFT?
General Dynamics Advanced Information Systems, Gilbert, Arizona.

WHAT DOES THE SCIENTIFIC COMMUNITY THINK OF THE GLAST MISSION?
The National Academies of Sciences ranked GLAST as the top-priority mid-sized project in its 2000 Decadal Survey of Astronomy and Astrophysics.

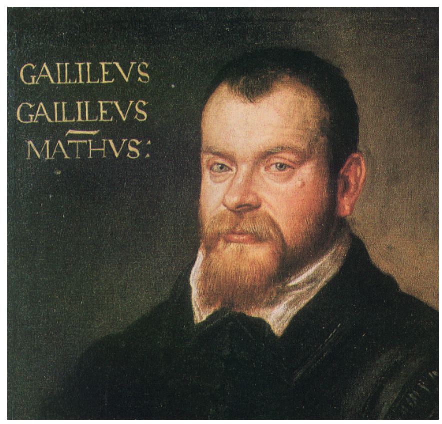
General Dynamics clean room, standing are: Chip Meegan, NASA Marshall Space Flight Center, Hunstville, Ala.; Peter Michelson, Stanford University, Stanford, Calif.; Steve Ritz, from NASA Goddard Space Flight Center, Greenbelt, Md. Kneeling are: Bill Atwood, University of California at Santa Cruz, Calif.; Dan Blackwood, NASA Goddard; Rick Harnden, NASA Headquarters, Washington; and Neil Johnson, Naval Research Laboratory, Washington. In the right corner, a technician checks the satellite. Credit: NASA and General Dynamics

HISTORY OF COSMIC DISCOVERY: OPENING NEW WINDOWS

By Robert Naeye

An old saying goes: Those who don't remember the past are condemned to repeat it. But research astronomers are quite content to repeat the history of their field, and for good reason. If there's one theme that has played itself out over and over in astronomy, it's the fact that whenever scientists open a new window on our Universe, or bring about a major upgrade in instrumentation, a period of remarkable discoveries is bound to follow. We can expect the same for GLAST.

A case in point dates back to dawn of the telescopic era. Although the telescope was invented in Holland, the great Italian Renaissance scientist Galileo Galilei was the first to systematically train this newfangled device on the heavens. In a short period of time starting in 1609, he revolutionized human understanding of our Universe. He discovered the four largest moons of Jupiter and the phases of Venus, which bolstered the Copernican view of a Sun-centered solar system. Galileo saw sunspots, mountains on the Moon, and the rings of Saturn. With just a tiny, crude telescope he resolved the Milky Way into "congeries of innumerable stars distributed in clusters."



Galileo Galilei (1564-1642). Credit: ESA

As astronomers built bigger and better telescopes during the 17th, 18th, and 19th centuries, they discovered new planets (Uranus and Neptune), new moons, asteroids, and entirely new classes of objects, including star-forming nebulae, planetary nebulae, "spiral nebulae," and binary stars. With improved optics, astronomers of the mid-1800s used the parallax method to make the first accurate measurements of the distances to other stars, proving that other celestial objects lie at immense distances from Earth. The development of spectroscopes in the late 19th century began to reveal the composition of stars.

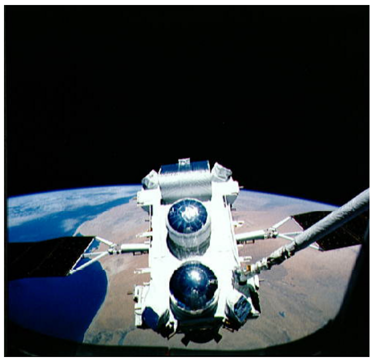
In the early 20th century, researchers developed a powerful one-two combination: photographic film coupled to the first truly large telescopes. Both advances enabled astronomers to see much fainter and deeper objects than ever before. In 1923-24, Edwin Hubble used the 100-inch telescope on California's Mount Wilson to prove that spiral nebulae were actually "island universes" — external galaxies unto themselves. Just five years later, Hubble discovered that our Universe is expanding, laying the foundations of modern Big Bang cosmology.

Arguably the most profound achievement of the 20th century, however, was the opening up of the entire electromagnetic spectrum, some of which is accessible only from space. Discoveries in radio, X-ray, and gamma-ray astronomy shattered the illusions of a sedate, slowly changing cosmos. We live in a Universe of explosions, collisions, and processes involving mind-boggling temperatures and energies that would have been incomprehensible to the astronomers of yesteryear.

Following in the footsteps of the pioneering work of Karl Jansky and Grote Reber in the 1930s and 40s, astronomers came to realize that the radio sky contained a wealth of information about the solar system, stars, galaxies, and even more exotic objects. Thanks to the opening of the radio window, astronomers discovered quasars, pulsars, the cosmic microwave background, the spiral structure of our Milky Way, dark matter, and incredible jets shooting away from the centers of large galaxies. NASA's missions such as COBE and WMAP have bolstered leading theories about the origin and possible future of our Universe.

In 1962, Riccardo Giacconi and several colleagues opened up yet another window when they launched a sounding rocket above the atmosphere. An X-ray detector picked up the powerful source Scorpius X-1 and a diffuse background glow of X rays. Subsequent balloon and rocket experiments, followed by satellites such as Uhuru, Einstein, ROSAT, Chandra, XMM-Newton, and Suzaku, have studied black holes, supernovae, relativistic jets, and active galaxies. For pioneering a new branch of astrophysics, Giacconi was honored with the 2002 Nobel Prize for Physics.

Also toward the end of the 20th century, scientists opened up the gamma-ray window, eventually leading to the discovery of gamma-ray bursts, gamma-ray blazars, cosmic-ray interactions, and other phenomena. Infrared astronomy is penetrating star-forming regions and yielding information about extrasolar planets and the disks that give birth to planets.



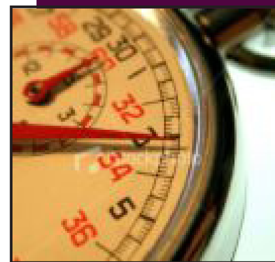
NASA's Compton Gamma-ray Observatory being deployed by the Space Shuttle in 1991. Credit: NASA

In recent times, the advent of precision spectrometers has enabled the discovery of more than 200 extrasolar planets. CCDs coupled to the new generation of 8- to 10-meter telescopes, and orbiting observatories such as the Hubble Space Telescope, are seeing back to an epoch when our Universe was just 1 billion years old. By catching supernovae in distant galaxies, these observatories have shown that our Universe's expansion is accelerating.

Various orbiting and ground-based observatories have opened up almost the entire electromagnetic spectrum, with unexpected discoveries coming with almost every step. But the gamma-ray spectrum from 10 to 100 gigaelectronvolts (GeV) is virtually unexplored. GLAST's primary science instrument, the Large Area Telescope (LAT), will fill in that gap. The EGRET instrument on NASA's Compton Gamma-ray Observatory saw hints of interesting and unexpected phenomena in that high-energy range, but GLAST will provide our first detailed look at that window. Expect a wealth of discoveries, and some big surprises, from GLAST!

Credit: Sonoma State University/Aurore Simonet

HISTORY



A TIMELINE OF GAMMA-RAY ASTRONOMY

By Robert Naeye and David Thompson

1950s MIT physicist Philip Morrison and others predict that cosmic rays interacting with interstellar material will produce gamma-ray emission from our galaxy.

Early 1960s The first balloon experiments, and NASA's Explorer 11 satellite, detect the first hints of 100 MeV gamma-ray emission from our galaxy, but the results are inconclusive. The lack of an easily detectable signal shows that the 1950's predictions were overly optimistic.

Early 1960s The first generation of ground-based Atmospheric Cherenkov Telescopes (ACTs) become operational in the U.S. and U.S.S.R. ACTs detect blue Cherenkov light created when very-high-energy (hard) gamma rays from space interact with molecules in Earth's atmosphere. The early ACTs yield inconclusive results, with no definitive detections.

Late 1960s U.S. military Vela satellites serendipitously detect gamma-ray bursts (GRBs) while looking for clandestine Soviet nuclear tests. But the existence of GRBs remains classified until 1973.

1967-1969 NASA's Orbiting Solar Observatory (OSO-3) detects a grand total of 621 gamma-ray photons from deep space, representing a major breakthrough. It verifies the existence of galactic emission from cosmic-ray interactions, and discovers the diffuse gamma-ray background. OSO-3 results are quickly confirmed by balloon experiments.

Early 1970s Gamma-ray detectors on the command modules for Apollo 15 and 16, while en route to the Moon, discover a diffuse background of low-energy gamma rays. These same instruments helped map gamma rays emitted from radioactive elements on the lunar surface.

1972 NASA's Small Astronomy Satellite-2 (SAS-2) confirms the diffuse gamma-ray background discovered by OSO-3. SAS-2 shows that the galactic emission is related to the structure of the Milky Way, it studies the Crab and Vela gamma-ray pulsars, and finds an unexpected point source, which later turns out to be the neutron star Geminga.

1975-1981 The European COS-B satellite, which is similar to SAS-2 in size and cost, discovers 25 additional gamma-ray point sources, some of which remain unidentified. Others turn out to be pulsars. Another one of the objects is the first extragalactic gamma-ray source: 3C 273, which is a relatively nearby quasar. It also detects diffuse galactic emission.

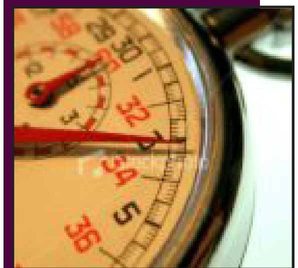
1979-1981 NASA'S High-Energy Astrophysics Observatory-3 (HEAO-3) discovers low-energy (soft) gamma rays coming from the galactic center from the annihilation of electrons and positrons. (This is the 511 keV line, which some scientists consider to be hard X rays.) Some still-unknown process must be producing antimatter in the region around the galactic center.

1980-1989 NASA's Solar Maximum Mission detects soft gamma rays from solar flares.

Late 1980s The second generation of ACTs becomes operational, led by the 10-meter Whipple Telescope in Arizona. Whipple indirectly detects hard gamma rays from the direction of the Crab Nebula, but not the pulsar at the center of the nebula.

Late 1980s Balloon experiments detect gamma rays from radioactive elements produced by Supernova 1987A, proving that supernovae produce new elements as predicted by theory.

Late 1980s NASA and the U.S.S.R. fly several dedicated missions to study GRBs, increasing the number of bursts and the number of theories about their origins.



1991-2000 The Compton Gamma-ray Observatory (CGRO), one of NASA's four Great Observatories, revolutionizes gamma-ray astronomy with a series of major discoveries. Designed for two years of operation, CGRO returns data for nine years, and is de-orbited because of a gyro-hardware failure. The BATSE instrument detects more than 2,700 GRBs and shows that they come from all over the sky, strongly suggesting they are explosions occurring in distant galaxies. It also shows that GRBs seem to occur in two types: long (greater than two seconds) and short (less than two seconds). The EGRET instrument finds 271 point sources, including about 70 blazars and six pulsars, but two-thirds of the sources remain unidentified. The discovery of so many blazars was unexpected. The COMPTEL instrument maps the galactic distribution of aluminum-26, showing where stars are forming in the Milky Way. The OSSE instrument maps the annihilation line from the galactic center more accurately, and finds gamma-ray emission from X-ray binaries and Seyfert galaxies.

Early 1990s Ground-based ACTs discover hard gamma rays from several blazars. To the amazement of astronomers, this emission varies on a timescale of just minutes to hours.

1997-2003 The Italian-Dutch BeppoSAX satellite, though mainly used to study X rays, localizes several GRB positions quickly through observations of the afterglows of long GRBs. The positions are precise enough that follow-up ground-based observations, and later observations from the Hubble Space Telescope, prove that the bursts occur at great distances, a major breakthrough.

2000-2007 NASA's High-Energy Transient (HETE-2) satellite helps firm up the connection between long GRBs and supernovae.

2002-present NASA's Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite continues to advance astronomers' understanding of how particles are accelerated and how energy is released in solar flares. RHESSI serendipitously detects polarization in a GRB, showing that powerful magnetic fields must be involved.

2002-present Among many other studies, the European Space Agency's International Gamma-Ray Astrophysics Laboratory (INTEGRAL) satellite measures aluminum-26 levels throughout our galaxy, demonstrating that the Milky Way produces, on average, about two supernovae per century.

2004-present NASA's Swift satellite is currently detecting about 100 GRBs per year, and localizing many of them for follow-up studies. The mission is showing that GRBs are more diverse than expected, and have a variety of origins. The follow-up of short GRB afterglows lends strong support to the theory that some of these events come from neutron star-neutron star mergers, or black hole-neutron star mergers.

2000s A new generation of advanced ground-based ACTs is providing unprecedented sensitivity and resolution in very-high-energy gamma-ray astronomy. Led by the European High Energy Stereoscopy System (H.E.S.S.), an array of four telescopes in Namibia, these detectors are finding pulsar-wind nebulae, binary systems, supernova remnants, and many unidentified sources. Other important ACTs include CANGAROO (an Australian-Japanese facility based in Australia), MAGIC (located on La Palma in the Canary Islands), and VERITAS (based in Arizona). MILAGRO (based in New Mexico) is using a large swimming pool full of photomultiplier tubes to conduct a survey of the gamma-ray sky. These ground-based experiments complement GLAST by extending detections to the highest gamma-ray energies.

2007 The Italian satellite AGILE launches on April 23. It has a high-energy gamma-ray detector with a sensitivity similar to EGRET's, but with a wider field of view.

2008 Launch of NASA's Gamma-ray Large Area Space Telescope (GLAST).

FEATURES: WHAT KINDS OF THINGS WILL GLAST STUDY?

Following are a list of things that GLAST will study, followed by a feature explaining each one, and how GLAST will explore it.

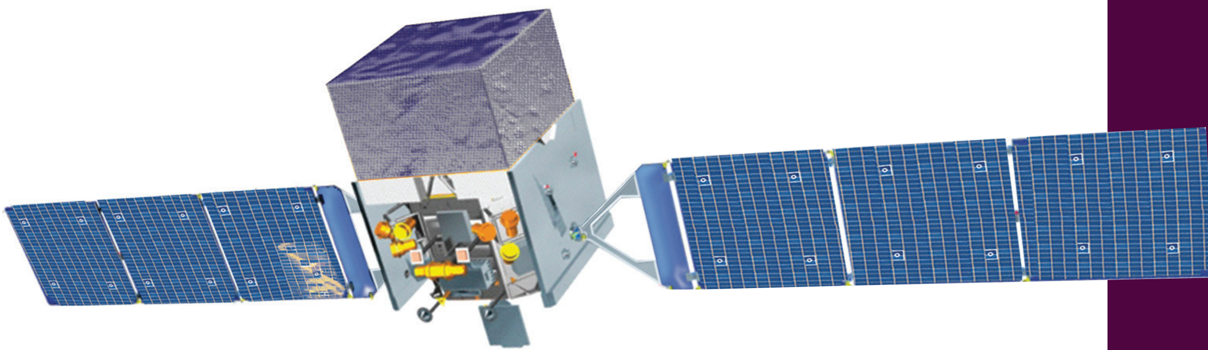


Image of the GLAST Satellite
Credit: NASA and Sonoma State University, Aurore Simonnet

1. **Blazars and Active Galaxies**
2. **Gamma-ray Bursts**
3. **Neutron Stars**
4. **Cosmic Rays and Supernova Remnants**
5. **Milky Way Galaxy**
6. **The Gamma-ray Background**
7. **The Early Universe**
8. **Solar System: Sun, Moon, and Earth**
9. **Dark Matter**
10. **Testing Fundamental Physics**
11. **Unidentified Sources and the Unknown**

1. Blazars and Active Galaxies

By Robert Naeye

GLAST will study a wide variety of astronomical objects and phenomena, but according to GLAST Project Scientist Steve Ritz of NASA's Goddard Space Flight Center in Greenbelt, Md., "Active galactic nuclei will be GLAST's bread and butter. There are guaranteed results."

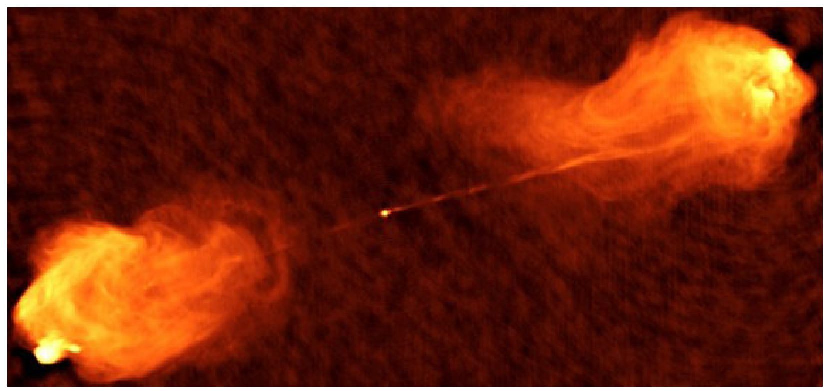
Active galactic nuclei, or AGN for short, are galaxies with extraordinarily luminous cores powered by black holes containing millions or even billions of times more material than our Sun. As gas is trapped by a monster black hole's gravity, it settles into an accretion disk and starts to spiral down the Universe's ultimate drain. Before the gas crosses the black hole's outer boundary (the event horizon) — beyond which nothing can escape — the material generates a vast outpouring of electromagnetic radiation. In the most luminous AGN, the visible light exceeds the combined output of an entire galaxy's worth of stars, even though the light-emitting area is only about the size of our solar system.

Even more amazing, radio, optical, and X-ray telescopes have resolved jets shooting away from galactic cores in opposite directions. The material in these jets can rip across space at more than 99% the speed of light, and some jets remain tightly collimated for hundreds of thousands of light-years. When a jet points almost directly toward Earth, the material can appear to be moving faster than the speed of light. This superluminal motion is an illusion caused by the geometry of a source moving at high speed that is nearly but not perfectly head-on.

But despite the staggering scale and speed of these jets, astronomers haven't been able to answer the most basic questions about them, such as how matter is accelerated to within a whisker of the speed of light. "We don't know what the jets are made of or how they are produced. It is one of the biggest unsolved mysteries of astrophysics. But jets are the link between the activity of the supermassive black hole and the AGN's surrounding environment in intergalactic space," says Peter Michelson of Stanford University in California, who is the Principal Investigator of GLAST's primary science instrument: the Large Area Telescope (LAT).

The LAT will probably detect gamma rays from different types of AGN, such as radio galaxies, Seyfert galaxies, quasars, and blazars. But the biggest contribution may come from blazars, which are thought to be AGN whose black holes aim their jets almost directly at Earth. Whereas the Energetic Gamma-Ray Experiment Telescope (EGRET) on NASA's Compton Gamma-ray Observatory identified 66 blazars during the mission, GLAST should see thousands. By studying the energy spectra and variability of gamma rays and other wavelengths of light coming from blazars, the LAT instrument should be able to determine the composition of the jets, establishing whether they are dominated by electrons and positrons (the antimatter counterpart of electrons), or by protons.

"When GLAST detects a blazar, it is monitoring violent activity from a black hole taking place in the distant past," says GLAST Interdisciplinary Scientist Charles Dermer of the Naval Research Laboratory in Washington, D.C. "Understanding gamma rays from these sources is a form of black hole archeology that reveals the high-energy history of our Universe."



In this radio image, two jets shoot out of the center of active galaxy Cygnus A. GLAST may solve the mystery of how these jets are produced and what they are made of.
Credit: NRAO

The LAT may also detect AGN that do not produce jets, or whose jets are not aimed directly at Earth. EGRET saw hints of gamma rays from at least two radio galaxies. The High Energy Stereoscopic System (H.E.S.S.), an array of four telescopes currently operating in Namibia, has discovered that gamma rays are coming from the giant elliptical galaxy M87, whose jets do not point toward Earth. These gamma-ray photons may originate from a region of the accretion disk very near the central black hole. By observing these and other galaxies, the LAT should provide precious insights into the mechanism that powers AGN activity.

Moreover, the LAT will investigate a curious discrepancy between EGRET and results from several ground-based observatories, including the Whipple Observatory in Arizona. EGRET detected low-energy gamma rays from blazars, whereas Whipple has discovered high-energy TeV-level gamma rays. "Ground- and space-based telescopes have detected blazars, but there is almost no overlap in the blazars they detect," notes GLAST Deputy Project Scientist Julie McEnery of NASA's Goddard. "Clearly, each type of telescope is seeing a different type of object."

With its ability to survey the entire sky every three hours, the LAT will undoubtedly catch many AGN giving off giant flares of energy, and this flaring is one of the most important tools for studying AGN. Blazars in particular are extremely variable at all wavelengths, changing both their total energy output and spectra on timescales ranging from less than an hour to many years. The relationship of variability at different wavelengths is a crucial test for models attempting to explain these outbursts and to identify the nature of the jet particles. Obtaining measurements across the spectrum is challenging, especially on short timescales, so GLAST team members will communicate with other astronomers, who can point various ground- and space-based telescopes at flaring blazars.

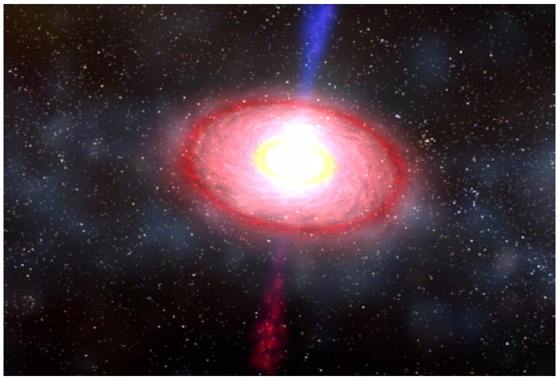
2. Gamma-ray Bursts

By Robert Naeye

Gamma-ray bursts (GRBs) were discovered by American surveillance satellites in the late 1960s. These satellites were looking for gamma rays coming from possible clandestine Soviet nuclear tests, but instead found brief but intense flashes of gamma rays coming from random directions in space.

To this day GRBs remain one of the greatest mysteries of modern astronomy. Despite lasting only a few milliseconds to several minutes, they are the brightest gamma-ray phenomena known, outshining all other sources of gamma rays combined. “An individual GRB can release in a matter of seconds the same amount of energy that our Sun will radiate over its 10-billion-year lifetime,” says GLAST Deputy Project Scientist Neil Gehrels of NASA’s Goddard Space Flight Center in Greenbelt, Md.

Astronomers have made considerable strides in recent years in understanding GRBs, progress that can be directly attributed to a series of spectacularly successful space missions. The Burst and Transient Source Experiment (BATSE) on NASA’s Compton Gamma-ray Observatory detected several thousand GRBs, and showed that they come from random directions on the sky — which strongly suggested that they are not of galactic origin and must occur at great distances. In the late 1990s, the Italian/Dutch BeppoSAX satellite was able to pinpoint the location of several GRBs, which enabled X-ray, optical, and radio telescopes to monitor their afterglows. This was a crucial development, since it enabled astronomers for the first time to measure distances to bursts and observe how they interacted with their surrounding environments. The now-defunct HETE-2 satellite and the currently operating NASA Swift satellite have significantly extended and improved these capabilities, and have lofted our study of GRBs to new heights.



Some gamma-ray bursts may result from a collision between two neutron stars or a black hole and a neutron star. This illustration depicts the turbulent aftermath of such a collision. Credit: Dana Berry / NASA

Thanks to these missions, astronomers now think that most GRBs, those lasting 2 seconds or longer (known as long GRBs), are associated with the explosive deaths of massive stars. As the star’s core collapses at the end of its life, it forms a black hole or neutron star. Computer simulations show that infalling stellar gas can tap the rotational energy of a rapidly spinning core, and magnetic fields can channel that material into two jets traveling at nearly the speed of light. These jets punch their way out of the dying star along its rotation axis. The gamma rays are produced by shock waves created either from material colliding within the jet, or from the jet slamming into surrounding material.

GRBs lasting less than 2 seconds (short GRBs) may originate from a variety of processes. Perhaps most are produced by the merger of two neutron stars, or the merger of a black hole and a neutron star. But others may be triggered by the collapse of the core of a massive star into a black hole, the collapse of a neutron star into a black hole, and powerful flares from magnetars (highly magnetized neutron stars).

But despite the new revelations from Swift and other missions, many crucial questions remain unanswered. What types of stars die as GRBs? What is the composition of the jets? How are the gamma rays in the initial burst produced? What is the total energy budget of a GRB? How does the central engine work? How wide are the jet opening angles? How do the jets interact with other material to produce the gamma rays? Swift has actually complicated the picture by showing that GRBs are much more diverse in their properties than astronomers had imagined prior to the spacecraft's launch in November 2004. As the saying goes, "If you've seen one GRB, you've seen one GRB." In fact, some GRBs don't seem to fall into either the long or short category and the origin of these "hybrid bursts" remains shrouded in mystery.

"GLAST is a multipurpose observatory designed to study many phenomena besides gamma-ray bursts, but it promises to greatly extend our knowledge of these incredibly powerful explosions," says Peter Michelson of Stanford University, who is the Principal Investigator of GLAST's Large Area Telescope (LAT).

The GLAST team specifically built the other science instrument, the GLAST Burst Monitor (GBM), to address this mystery. "The GBM will detect approximately 200 GRBs per year," says GBM Principal Investigator Charles "Chip" Meegan of NASA's Marshall Space Flight Center in Huntsville, Alabama. "It's amazing that gamma-ray bursts are so powerful that a small detector you could hold in one hand can observe them from distances of billions of light-years."

The GBM and the LAT will work in tandem to attack the problem of GRBs. If the GBM picks up an interesting GRB in a part of the sky that is not in the LAT's field of view at that moment, the spacecraft will slew autonomously so the LAT can study the burst in more detail. The GBM will pick up X rays and gamma rays with energies ranging from 8 keV to 30 MeV. The LAT can pick up gamma rays ranging from 20 MeV to 300 GeV. Former GBM Co-principal Investigator Giselher Lichti of the Max Planck Institute for Extraterrestrial Physics, which built the GBM detectors, notes that the GBM and the LAT together cover an energy range extending from about 10 keV to 300 GeV. "That's seven orders of magnitude in energy coverage for GRBs," he notes. "That exceeds the energy range covered by Swift enormously, thus yielding a wealth of new information about GRBs." The seven orders of magnitude in energy corresponds to 23 octaves on the musical scale, or the equivalent of four full-size piano keyboards side by side.

The LAT's high-energy coverage will give astronomers precious insight into an energy realm that so far has been poorly studied. The Compton Gamma-ray Observatory's Energetic Gamma-Ray Experiment Telescope (EGRET) instrument detected a handful of extremely high-energy gamma rays from a few GRBs. These photons did not seem to behave the same way as those detected at lower energies by the spacecraft's BATSE instrument. Strangely, one of the highest-energy gamma rays arrived at EGRET 90 minutes later than lower-energy gamma rays arrived at BATSE. What causes this delayed emission? GLAST's observations may tell the tale. "We don't understand the very-high-energy range very well; it's bizarre," says GLAST Project Scientist Steve Ritz of NASA's Goddard. "That energy range will tell us about the GRB's central engine, so the LAT and the GBM together may be able to tell us how GRBs actually work."

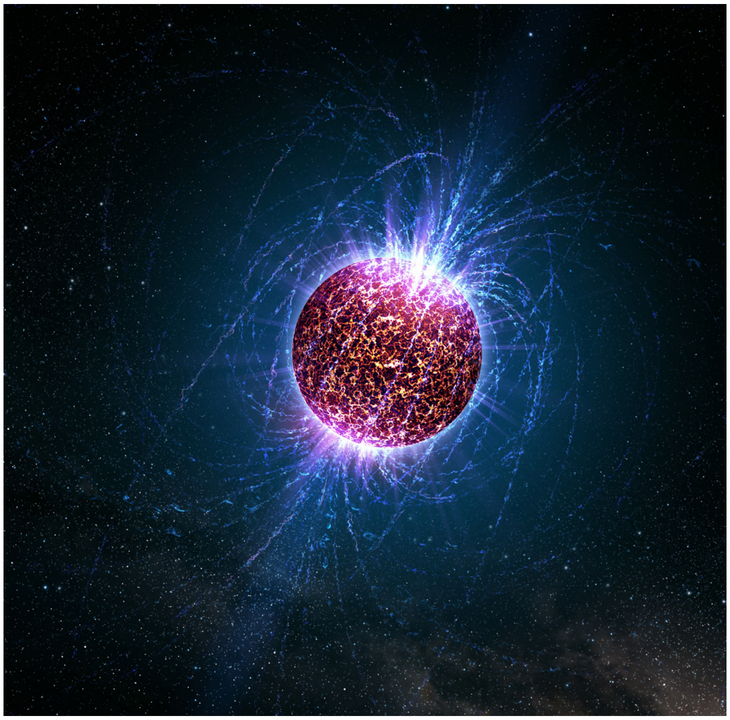
Meegan points out that some bursts actually exploded when the Universe was less than a billion years old. "In fact, we may be seeing back to when the first stars formed," he says. "GRBs may thus turn out to be our best window to the infancy of the Universe."

3. Neutron Stars

By Robert Naeye

When the core of a massive star undergoes gravitational collapse at the end of its life, protons and electrons are literally scrunched together, leaving behind one of nature's most wondrous creations: a neutron star. Neutron stars cram roughly 1.3 to 2.5 solar masses into a city-sized sphere perhaps 20 kilometers (12 miles) across. Matter is packed so tightly that a sugar-cube-sized amount of material would weigh more than 1 billion tons, about the same as Mount Everest!

"With neutron stars, we're seeing a combination of strong gravity, powerful magnetic and electric fields, and high velocities. They are laboratories for extreme physics and conditions that we cannot reproduce here on Earth," says Large Area Telescope (LAT) science team member David Thompson of NASA's Goddard Space Flight Center in Greenbelt, Md.



Given their nasty environments, neutron stars would rank near the bottom of the list of interstellar vacation destinations. But they are a boon to GLAST scientists, who will study them as natural laboratories for some of our Universe's most extreme physics. The gravity of these stellar corpses compresses matter to extraordinary densities, and warps the surrounding space-time. Ultrapowerful magnetic fields accelerate particles to speeds approaching that of light.
Credit: Casey Reed / Penn State University

Most known neutron stars belong to a subclass known as pulsars. These relatively young objects rotate extremely rapidly, with some spinning faster than a kitchen blender. They beam radio waves in narrow cones, which periodically sweep across Earth like lighthouse beacons. But as GLAST Project Scientist Steve Ritz of NASA's Goddard points out, "With magnetic fields trillions of times stronger than Earth's, pulsar magnetic fields are high-energy particle accelerators." The magnetospheres of some pulsars accelerate particles to such high energies that they are relatively bright gamma-ray sources. Astronomers have found less than 2,000 pulsars, yet there should be about a billion neutron stars in our Milky Way Galaxy. There are two reasons for this shortfall. One is age: most neutron stars are billions of years old, which means they have plenty of time to cool and spin down. Without much available energy to power emissions at various wavelengths, they have faded to near invisibility. But even many young pulsars are invisible to us with radio telescopes because of their narrow lighthouse beams. "Because pulsar beams are much broader in gamma rays, GLAST will allow us to detect some of the youngest, most energetic pulsars in our galaxy," says GLAST Interdisciplinary Scientist Stephen Thorsett of the University of California, Santa Cruz. "Getting a much more complete sample of the Milky Way's population of neutron stars is one of the most important ways that GLAST will advance our understanding of the life cycle of stars."

The EGRET instrument on NASA's Compton Gamma-ray Observatory saw six pulsars, but the LAT has the sensitivity to find dozens or perhaps hundreds. Among these discoveries, scientists hope to find pulsars similar to Geminga, which is relatively bright in gamma rays but is strangely quiet in radio waves, perhaps because its radio beam doesn't point toward Earth. Geminga is roughly 300,000 years old, which makes it middle-aged in the pulsar life cycle. If it weren't so close to Earth (about 500 light-years), EGRET would not have seen it. The LAT will be able to see much fainter pulsars, many of which will be much older than Geminga. Pulsars spin-down as they age, and this should weaken particle acceleration, which in turn should cause their gamma-ray flux to weaken. The LAT should thus be able to tell scientists about this rate of decline, which in turn will yield precious clues about the particle-acceleration mechanism.

Finding new gamma-ray pulsars will be nice, but as LAT science team member Alice Harding of NASA's Goddard notes, "GLAST is really about studying the physics of these sources." For example, GLAST will probably be able to determine whether pulsar magnetic fields are so strong that gamma-ray photons packing more than about 4 or 5 GeV of energy can transform themselves into pairs of particles and antiparticles. EGRET observations suggest this process might be occurring in the magnetosphere of a pulsar in the constellation Vela. But EGRET did not have enough sensitivity at high gamma-ray energies to see if there is a sharp cutoff in gamma rays above 4 or 5 GeV. In the LAT's first few months of operation, it should be able to see if the Vela pulsar exhibits this sharp cutoff — an unambiguous signature of pair production. "A neutron star is the only place where we can measure this effect," says Harding.

EGRET observations showed that gamma rays dominate the total radiation emitted by young pulsars, which are rapidly spinning down. Moreover, EGRET data showed that variations in the high-energy gamma-ray emission probably arise from the changing view into the pulsar magnetosphere as the neutron star spins. The LAT will have the ability to map pulsar magnetospheres and provide unique information regarding the physics of the pulsed emission, and perhaps even answer the long-standing mystery of how the pulses are actually produced.

By monitoring the pulses of extremely fast rotators, known as millisecond pulsars, which rotate hundreds of times per second, GLAST will probably observe effects due to special relativity. "The pulses are so distorted by relativistic effects that we have to filter all of those out to figure out what's really happening at the pulsar itself," says Harding. She notes that these observations might dispel the common "lighthouse" model of pulsars, showing that what we see is really a relativistic distortion of the pattern emitted by the pulsar.

GLAST will also advance scientists' understanding of how pulsars generate particle winds, and how these winds interact with the surrounding medium. The LAT may find several dozen new examples of pulsar wind nebulae, and provide much more detailed observations of the only example seen by EGRET: the one surrounding the pulsar in the Crab Nebula. Virtually nothing is known about the gamma-ray emission of pulsar wind nebulae in the region between 10 and 100 GeV, and yet that might be where most of the exciting action is taking place. The LAT will fill in that gap.

GLAST's other main instrument, the GLAST Burst Monitor (GBM), will likely pick up extremely energetic flares from neutron stars with ultra powerful magnetic fields. These so-called magnetars occasionally unleash flares that pack more energy in a fraction of a second than the Sun will emit in tens of thousands or even hundreds of thousands of years. The flares are probably ignited when a massive shift in the crust (a starquake) triggers a large-scale untwisting and rearrangement of magnetic-field lines, causing them to snap and release vast amounts of pent-up magnetic energy in the form of gamma rays, X rays, and particles.

But theorists lack a detailed understanding of this process. NASA's Swift satellite has detected several of these events, including a superflare from the magnetar SGR 1806-20 on December 27, 2004.

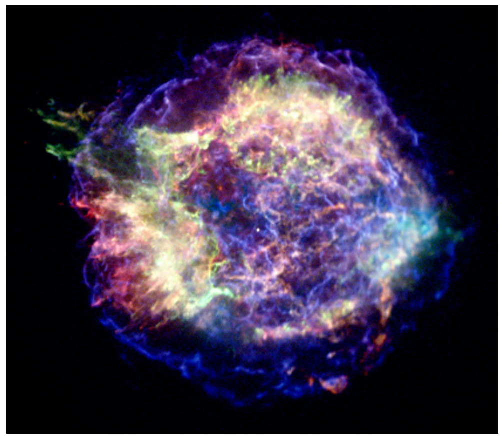
The GBM and the LAT combined cover a much wider range of energies than Swift, so when combined with observations from other spacecraft, scientists may be able to assemble a more detailed picture of what powers these incredible outbursts.

4. Cosmic Rays and Supernova Remnants

By Robert Naeye

In the early 1900s, Austrian physicist Victor Hess discovered that particles from deep space incessantly bombard Earth's atmosphere, producing showers of secondary particles that reach the surface. In one of the great misnomers of science, these particles came to be known as "cosmic rays." But in reality, they have nothing to do with light rays. Instead, they are subatomic particles that have been accelerated to nearly the speed of light by energetic astrophysical processes whose sources have remained a mystery.

But after GLAST's Large Area Telescope (LAT) collects data for a few years, there's a very good chance that scientists will solve at least part of this mystery. For decades, scientists have pointed to a likely culprit for the acceleration of lower-energy cosmic rays: supernova remnants. These gaseous structures form when blast waves from exploding massive stars plow through interstellar material and sweep it up into shells. The shock waves that form in supernova remnants have the right amounts of energy to accelerate protons and other particles to the levels of energies measured in the lower-energy cosmic rays striking Earth's upper atmosphere. Previous X-ray observations strongly suggest this is actually occurring.



This deep Chandra image shows Cassiopeia A (Cas A for short), the youngest known supernova remnant in the Milky Way.
Credit: NASA/CXC/MIT/UMass Amherst/ M.D.Stage et al.

IMAGE AT"Cosmic rays, the highest-energy particles in nature, are thought to be formed when stars collapse and produce tremendous shock waves. GLAST will test this theory by measuring the spectra of gamma rays from the remnants of supernovae, where cosmic rays should be abundant," says GLAST Interdisciplinary Scientist Charles Dermer of the Naval Research Laboratory in Washington, DC.

"The theory all seems right, but we've never been able to prove it. The LAT might just be the telescope that's able to do it," adds LAT science team member David Thompson of NASA's Goddard.

According to theory, shock waves in supernova remnants can accelerate protons to energies 1,000 times higher than can be achieved by the largest particle accelerators on Earth. The protons then collide with nearby interstellar material, producing a cascade of secondary particles known as pions (which are more massive than electrons, but less massive than protons and neutrons). Neutral pions (those lacking an electric charge) decay quickly into gamma rays of a characteristic energy around 67 MeV, ideal for detection with the LAT.

When previous gamma-ray observatories looked toward the galactic plane, they saw an increase in gamma-ray flux right around 67 MeV, which proves that cosmic-ray particles are interacting with interstellar material throughout the Milky Way. "But we want to see that on a local scale," says Thompson. "We want to see it happening at the sources, which are thought to be supernova remnants. The LAT has the sensitivity and spatial resolution to do the job."

The LAT's energy range, however, is many orders of magnitude too low to enable scientists to decipher the origin ultra-high-energy cosmic rays, one of the great unsolved mysteries in astrophysics.

5. Milky Way Galaxy

By Robert Naeye

Not counting transient events such as gamma-ray bursts, the brightest object in the gamma-ray sky is the plane of our Milky Way Galaxy. This glow results from a vast sea of cosmic-ray particles slamming into interstellar gas and dust, generating gamma rays. In fact, 75% of the gamma rays in our galaxy come from these cosmic-ray interactions. This bright gamma-ray glow gives the GLAST science team a golden opportunity to study the structure, composition, and dynamics of the interstellar material that pervades our home galaxy.

But as Large Area Telescope science team member David Thompson of NASA's Goddard, explains, "It's not easy to understand something when you're in the middle of it." Adding to the complexity is the fact that our galaxy is filled with many different types of particles and energy sources, including protons, electrons, electromagnetic radiation, magnetic fields, and so forth — most of which have not been accurately measured.

Artist's concept of the Milky Way Galaxy. GLAST will provide detailed information on where stars are forming.
Credit: NASA JPL

To study our galaxy, theorists create models of how these different particles interact with magnetic fields in different locations and with different strengths. Astronomers can then compare these models to actual observations made at radio, infrared, optical, ultraviolet, and X-ray wavelengths to see how well they match the data. The LAT will contribute vital data that will enable theorists to constrain and improve their models.

For example, the EGRET instrument on NASA's Compton Gamma-ray Observatory saw hints that there may be clumps of gas in our galaxy that are not seen by radio telescopes. GLAST observations of the galactic plane should be able to help astronomers pin down whether or not these clumps are real. They might also reveal changes in the interstellar medium due to recent supernovae.

Having an accurate model of gamma-ray production within our galaxy is not only important in its own right, it is vital for the measurement of localized gamma-ray sources. The sources are seen against the bright background of the Milky Way glow. If the galaxy is not modeled correctly, then information about other objects could be distorted. As GLAST Program Scientist F. Rick Harnden Jr. notes, "The same gamma rays that measure galactic structure are also a background for other observations."

6. The Gamma-ray Background

By Robert Naeye

From as far back as the late 1960s, orbiting observatories have found a diffuse background of gamma rays streaming from all directions. "If you had gamma-ray vision and looked at the sky, there would be no place that would be dark," says Large Area Telescope (LAT) team member David Thompson of NASA's Goddard.

To this day, astronomers have not pinned down the source of this gamma-ray background. The leading candidates are unresolved active galactic nuclei (AGN), especially blazars. NASA's Chandra X-ray Observatory discovered, for example, that dust-enshrouded AGNs were responsible for a background glow seen in X rays. But astronomers don't know enough about AGN and their gamma-ray-emitting properties to say with absolute certainty that AGNs are the source of the gamma-ray background. It's quite likely that ordinary galaxies similar to our Milky Way are also an important component of the background, since they have the same cosmic-ray interactions with interstellar material that light up the plane of our galaxy.

The LAT has high enough sensitivity and spatial resolution that it should be able to confirm whether or not AGNs and ordinary galaxies are the culprit. LAT science team members will be able to correlate specific gamma-ray sources with objects seen at other wavelengths. They will also be able to measure the spectral properties of faint LAT sources to see if they match those of blazars.

"We should also be able to see starburst galaxies," says GLAST Deputy Project Scientist Julie McEnery of NASA's Goddard. These are galaxies that are forming stars in huge numbers. The most massive of these stars evolve quickly and explode as supernovae, producing swarms of cosmic rays in the process. "The gamma-ray flux from a galaxy should be a measure of the total energy flux from that galaxy. The LAT can try to verify that relationship between supernovae and the gamma-ray flux," adds McEnery.

Starburst galaxies such as NGC 253, shown here, probably make up part of the gamma-ray background.
Credit: Robert Gendler/Jim Mistin

"If the background is not unresolved point sources, this would be a huge discovery, and would probably mean the glow is cosmological in origin," says GLAST Project Scientist Steve Ritz of NASA's Goddard. If AGNs and ordinary galaxies are not responsible, it could be the result of dark-matter particles annihilating one another or chain reactions caused by ultra-high-energy cosmic rays interacting with interstellar gas. Or it could come from a process that no one has yet conceived. But as Thompson says, "Occam's razor dictates that we first test the obvious before going to the exotic."

7. The Early Universe
By Robert Naeye

It may seem counterintuitive, but GLAST — a gamma-ray observatory — may provide crucial information about the amount of visible and ultraviolet light being emitted by the first stars to form in the Universe. It will be able to study this problem because, as LAT science team member David Thompson of NASA's Goddard, explains, "Einstein's equation $E = mc^2$ works both ways."

In other words, matter can be converted into energy (in the form of electromagnetic radiation), but energy can also be converted into matter. If a gamma-ray photon interacts with another photon, and if the two photons combined have a high enough energy, they can combine to become an electron and its antimatter counterpart, a positron. Visible-light and ultraviolet photons have enough energy to combine with gamma rays to make these interactions possible. The first generations of stars and galaxies must have bathed the early Universe in visible and ultraviolet photons, making such interactions probable enough that GLAST's Large Area Telescope (LAT) should easily be able to detect this effect by seeing blazars fading and disappearing as it looks further and further back in time.

The effect depends greatly on a gamma ray's energy, since the higher a photon's energy, the more likely it is that it will meet another photon that it can interact with (or smash into) and produce matter particles. For example, below the energy of 1 GeV, a gamma ray can reach Earth from a redshift of 6 or higher, so LAT should be able to detect gamma-ray sources at those distances. (Redshift is a measure of how much an object's light has been "stretched" by cosmic expansion, so the higher an object's redshift, the further back we see it in time. A redshift of 6 corresponds to an era about 1 billion years after the Big Bang.) But gamma rays with energies of 100 GeV or higher should be absorbed en route to Earth if they originated from a source (such as a blazar) with a redshift of 6 or higher.

"GLAST will be able to measure how the amount of visible and ultraviolet light in the Universe changed over time by observing the gamma-ray flux as a function of distance and energy," says GLAST Project Scientist Steve Ritz of NASA's Goddard. "This effect kicks in at lower energies and greater distances."

The EGRET instrument on NASA's Compton Gamma-ray Observatory wasn't sensitive enough to see enough very distant blazars and other gamma-ray sources to study this problem. In addition, it couldn't detect gamma rays with high enough energies to provide meaningful results. "But the LAT has both capabilities, so it can do this experiment," says Thompson. "It will give us a clue about the source of light in the very early Universe. This is an exciting prospect."

"The more stars that formed in the early Universe, the more absorption of gamma rays," adds Floyd Stecker of NASA's Goddard. "These measurements will give us a handle on what happened in the distant past, which is why I call it photon archaeology."

8. Solar System: Sun, Moon, and Earth

By Robert Naeye

Ordinary stars are simply not energetic enough to generate detectable levels of gamma rays. The one exception is the Sun, but only because of its close proximity to Earth. "If you exclude flares, the Sun is pretty quiet," says LAT science team member David Thompson of NASA's Goddard.

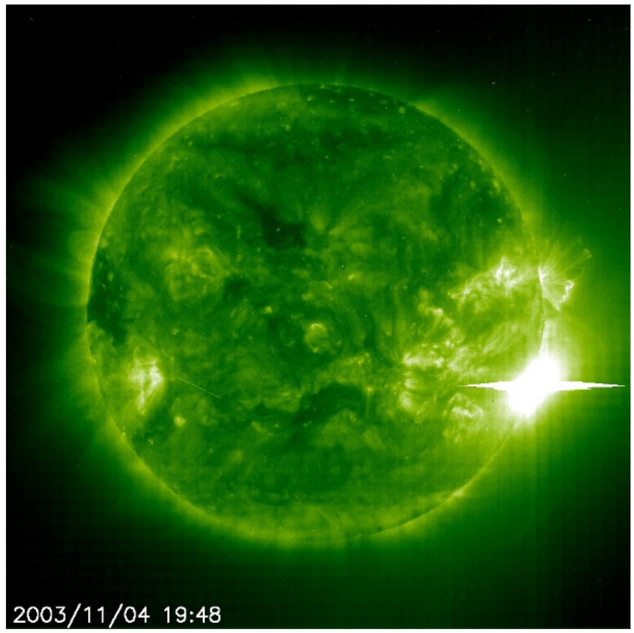
But the Sun, of course, sporadically unleashes powerful flares, which spew particles into the solar system at high velocities. These flares can turn our star into an extremely bright gamma-ray source for several hours. Even though astronomers have studied solar flares for decades, they still don't know how the Sun generates these outbursts. Astronomers also lack a detailed understanding of how the Sun accelerates particles that produce the gamma rays seen in flares.

GLAST could lead to important breakthroughs in this area. It will complement NASA's Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) mission, a satellite launched in 2002. RHESSI detects solar-flare gamma rays with energies up to about 20 MeV. The LAT will extend this range to higher than 300 GeV, which will enable astronomers to test theories that have been developed based on data from RHESSI and other instruments.

The timing of the GLAST mission is ideal for solar studies, since the Sun recently passed through a minimum in its 11-year sunspot cycle. Solar activity is beginning to increase, and is expected to peak around 2011 or 2012. "No other instrument will be available to observe the Sun in the LAT's energy band during the upcoming solar maximum," says solar physicist Gerald Share of the University of Maryland, College Park.

Solar flares will also trigger the GLAST Burst Monitor (GBM), which covers an energy range that overlaps that of RHESSI. "The GBM may detect more than 100 flares containing nuclear radiation during this new cycle, Solar Cycle 24," adds Share.

Scientists will use LAT and GBM data to test theories of flare production. According to most current theories, flares are produced when solar magnetic-field lines snap and then reconnect. These processes release staggering amounts of energy, and they could accelerate particles to energies high enough to produce gamma rays. Some solar flares produced such intense gamma-ray emission that they saturated the EGRET instrument on NASA's Compton Gamma-ray Observatory. But with its more modern design, the LAT should provide crucial data that will help fill in the gaps in our understanding of solar flares and particle acceleration. Improved understanding of space weather, in turn, will make future human space missions safer. "Solar-flare particles can cause severe damage to satellites, and to astronauts if they are not protected," says Thompson.



The Sun unleashed a flare on November 4, 2003 that could be one of the most powerful ever witnessed. GLAST will shed considerable light on the origin of these explosions and how particles are accelerated. Credit: NASA SOHO

GLAST will even be able to detect gamma rays coming from the Sun during the quiet phases of its 11-year cycle. These gamma rays come from cosmic rays impacting the Sun. GLAST studies of the Sun's quiescent phase should tell scientists quite a bit about the solar magnetic field

GLAST may also yield interesting results pertaining to other solar-system bodies. Surprisingly, the Moon is a moderately bright gamma-ray source. As Thompson says, "The only part of the electromagnetic spectrum where the Moon is brighter than the Sun is gamma rays."

Being a cold, mostly inert object, the Moon is utterly incapable of producing gamma rays on its own. But cosmic-ray particles slamming into the lunar surface produce secondary gamma rays. The LAT will watch the Moon change position from hour to hour as it orbits Earth. The LAT will see higher-energy gamma rays emanating from the Moon than could be seen by EGRET, and the LAT's spatial resolution is superior. However, scientists are not anticipating any dramatic discoveries.

Earth itself is also a bright gamma-ray source. Fortunately for us, our planet's magnetic field and atmosphere prevent gamma rays from hitting the surface. But cosmic-ray interactions produce a steady and significant flux of gamma rays in the upper atmosphere. For the most part, the LAT will be looking away from Earth to avoid this emission. The BATSE instrument on Compton picked up low-energy gamma rays associated with lightning storms, along with energetic atmospheric phenomena at higher altitudes, such as jets and sprites. The GBM, and possibly even the LAT, will pick up many of these events.

Other solar-system objects are probably either too small or too far away to be detectable by GLAST.

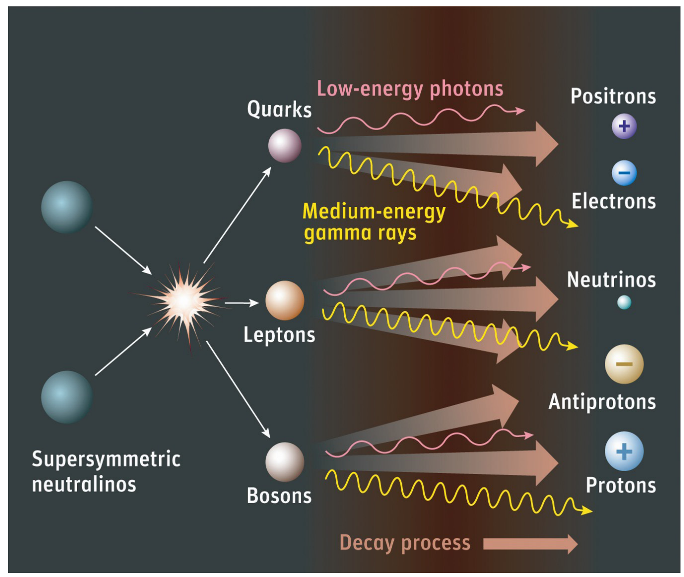
9. Dark Matter

By Marcus Woo, Freelance Science Writer

The identity of dark matter — the mysterious stuff that makes up about 22% of the Universe's energy contents — continues to elude scientists decades after they first inferred its existence. The leading candidate that might explain the fundamental make-up of dark matter is a hypothetical particle called the weakly interacting massive particle, or WIMP. But with GLAST, scientists may finally find clear evidence that dark matter is indeed made of WIMPs.

Gamma rays originate from a multitude of high-energy sources, such as black holes and exploding stars. But current theory suggests they can also come from WIMPs, which are massive particles that do not emit or absorb light. Such particles are predicted by supersymmetry, a theory that extends the highly successful Standard Model of particle physics.

According to supersymmetry, WIMPs act as their own antimatter particles. When two WIMPs interact, they annihilate each other and release a flurry of secondary particles as well as gamma rays. Using GLAST, scientists hope to find these high-energy signatures of dark matter in our galaxy. If they succeed, this discovery will help solve one of astronomy's grandest mysteries.



According to supersymmetry, dark-matter particles known as neutralinos (which are often called WIMPs) annihilate each other, creating a cascade of particles and radiation that includes medium-energy gamma rays. If neutralinos exist, the LAT might see the gamma rays associated with their demise.
Credit: Sky & Telescope / Gregg Dinderman.

"With GLAST, we hope to actually see individual dark-matter annihilations," says theoretical physicist Michael Peskin of the Stanford Linear Accelerator Center (SLAC). Ted Baltz, a Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) researcher who also works on GLAST, adds, "GLAST has the real possibility of making a fundamental contribution to understanding what galaxies are made of."

Even though dark matter interacts much more weakly than ordinary matter, dark matter is not spread out evenly through space and should form clumps in and around galaxies. If dark matter is in fact composed of WIMPs, this clumping would improve the chances of these particles meeting and annihilating, producing steady streams of gamma rays detectable by GLAST's Large Area Telescope.

The trick will be distinguishing gamma rays produced by dark-matter annihilations from those generated by numerous other sources in the Universe. To differentiate between the two, researchers have established a set of four guidelines:

- Supersymmetry predicts that WIMP annihilations will create gamma rays of particular wavelengths, distinct from those generated by other sources such as black holes or supernovae.
- Dark-matter annihilations should produce gamma rays exclusively, ruling out interactions that involve other forms of radiation.

- These signals should appear to GLAST not as point sources, but as large patches in the sky — some nearly twice as big as the full Moon.
- These streams of gamma rays should be continuous, a marked difference from the fleeting explosions of gamma-ray bursts, which last only a few milliseconds to several minutes.

If scientists find a signal with all of these characteristics, chances are good that they have found a source of WIMP annihilation.

GLAST will be running in parallel with numerous other dark-matter experiments, such as searches for WIMP collisions in underground detectors and attempts to manufacture WIMPs at the Large Hadron Collider (LHC) at the European Center for Nuclear Research (CERN) in

Switzerland starting in 2008. Given this activity, many scientists are confident the existence of WIMPS will be confirmed or refuted in the next few years.

"If GLAST detects these signals, it will be enormously important for both particle physics and astrophysics. It will represent a huge intellectual achievement and a big leap forward in our understanding of the Universe on the largest and smallest scales simultaneously," said Lynn Cominsky of Sonoma State University in Rohnert Park, California, leader of GLAST's education and public outreach team.

10. Testing Fundamental Physics
By Robert Naeye

GLAST covers an energy range that will allow science team members to make sensitive tests of fundamental physics, perhaps finding violations to some of the field's most cherished tenets. But as GLAST Deputy Project Scientist Julie McEnery of NASA's Goddard cautions, "This is not guaranteed science; this is somewhat speculative."

For example, GLAST will be able to test whether light travels at the same speed in a vacuum regardless of wavelength. According to Albert Einstein's special theory of relativity, all electromagnetic radiation should travel at the same speed, which has been measured to be 299,792,458 meters (186,282.4 miles) per second. In other words, high-energy gamma-ray photons should zip across space at exactly the same speed as low-energy radio photons.

But some models of quantum gravity, which attempt to merge Einstein's general theory of relativity with quantum mechanics, predict that extremely high-energy gamma rays could travel at a slightly different speed than other forms of light. According to quantum mechanics, space-time becomes turbulent at tiny scales, as quantum fluctuations cause virtual particle-antiparticle pairs to continually form and annihilate. If quantum fluctuations also produce tiny black holes, as suggested by some versions of quantum gravity, very-high-energy gamma rays have such short wavelengths that they might actually "feel" this quantum turbulence, which could slightly boost or retard their velocity.

Credit: NASA

"GLAST may be able to test this prediction by running a very long race of 10 billion light-years," says GLAST Project Scientist Steve Ritz of NASA's Goddard. If very-high-energy gamma rays from GRBs preferentially arrive at Earth slightly ahead of or behind low-energy gamma rays, this could indicate a violation in the principle that all light travels at the same speed in a vacuum. Even if GRBs tend to release high-energy gamma rays slightly before or after low-energy

FEATURES

gamma rays, GLAST could notice that the lag time gets larger as GRB distances increase. "If this happens, and if we can exclude more mundane astrophysical explanations, this would be a huge discovery," says Ritz. "GLAST would truly carry us beyond Einstein."

GLAST could conceivably see the evaporation of tiny black holes — weighing around 10^{14} grams (100 million tons) — that formed moments after the Big Bang. At that time, the density variations in the Universe might have been high enough to allow small regions to collapse gravitationally into small black holes. Nobody knows whether such primordial black holes actually formed, but if they did, some might still be around in the Universe today. As first described by Stephen Hawking and others in 1974, black holes theoretically have finite lifetimes because they radiate away their mass in a quantum process. They literally evaporate into ordinary particles. The evaporation rate increases as the black-hole mass decreases, which explains why Hawking radiation is unobservable from stellar-mass black holes. At the end of their lives, tiny black holes undergo a runaway explosion into a shower of gamma rays and other particles. It's possible that GLAST could detect gamma rays emitted by exploding black holes, and that would be a spectacular confirmation of the connection between quantum mechanics and general relativity.

The LAT might also pick up a strange phenomenon predicted by quantum theory, but which has only been observed in the laboratory: photon splitting. A very-high-energy gamma-ray photon could literally split into two lower-energy photons by tapping into a surrounding energy reserve, such as a neutron star's magnetosphere. Compton Gamma-ray Observatory observations of the pulsar B1509-58 provided tantalizing hints for this process. GLAST observations of this and other pulsars could provide strong evidence that photon splitting is actually occurring in nature.

11. Unidentified Sources and the Unknown

By Robert Naeye

GLAST is certain to make contributions in a number of areas, such as the study of active galactic nuclei, gamma-ray bursts, and neutron stars. But for GLAST science team members, perhaps the most tantalizing possibility is the prospect of finding something entirely new and unexpected. "This is a relatively unexplored field, so the potential for major discoveries is very high," says LAT science team member David Thompson of NASA's Goddard.

The history of astronomy shows that whenever instruments open a new window to the Universe, or make an order of magnitude improvement in capability, major discoveries almost always follow, often including the discovery of new classes of objects. GLAST represents such a giant leap over all previous gamma-ray satellites that it is not unrealistic to expect revolutionary findings (see article on pages 13-14).

A case in point can be seen when GLAST is compared to the EGRET instrument on NASA's Compton Gamma-ray Observatory. EGRET logged 271 gamma-ray sources. But 172 of them — nearly two-thirds — remain unidentified, because EGRET could not pinpoint their location with sufficient precision to enable astronomers to associate them with known objects. "Since GLAST's Large Area Telescope (LAT) can localize many objects to better than 1 arcminute, astronomers will be able to identify most of those sources," says GLAST Project Scientist Steve Ritz of NASA's Goddard.

Many of the unidentified point sources are probably in other galaxies — blazars. But a considerable number of the unidentified sources lie along the galactic plane, meaning that in all likelihood, they belong to our Milky Way Galaxy. Many of these sources are probably pulsars, whereas others could be supernova remnants, binary systems containing a black hole or neutron star, stars with powerful winds, or nebulae sculpted by pulsar winds. Some of the unidentified extragalactic sources may turn out to be clusters of galaxies, starburst galaxies, or ultraluminous infrared galaxies (known as ULIRGs). LAT observations should be able to pin down the nature of most of these objects. But as Thompson says, "There are surprises out there waiting to be found. Frankly, we're hoping to be surprised when it turns out to be none of the above."

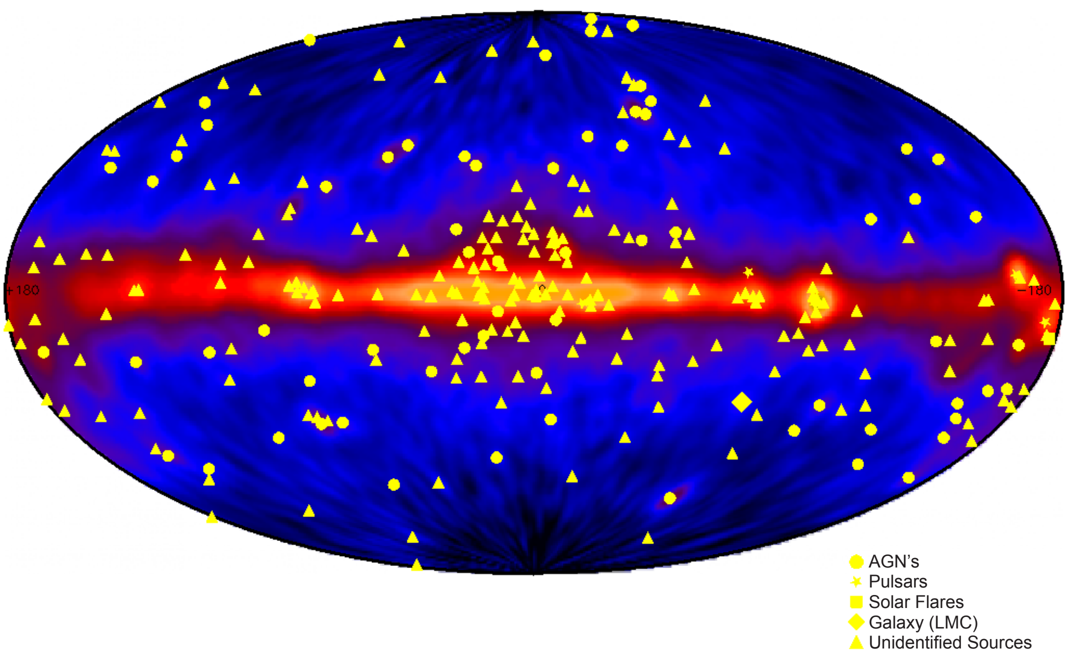
And because of the LAT's major upgrade in sensitivity over EGRET, GLAST should see thousands of new point sources. "It might see 3,000 point sources, or it might see 9,000; we just don't know. But we're looking forward to the answer," says GLAST Project Scientist Steve Ritz of NASA's Goddard.

GLAST Burst Monitor (GBM) Principal Investigator Charles "Chip" Meegan of NASA's Marshall Space Flight Center in Huntsville, Alabama, echoes this assessment: "Although we can

anticipate some of the things that the GBM and the LAT will see, the most exciting results will be the surprises that always come from seeing what was previously invisible."

"It will be interesting to see how wrong this all is after one or two years of taking data," adds GLAST Deputy Project Scientist Julie McEnery of NASA's Goddard. "I hope we are wrong on a lot of things, since it implies that the sky has surprises."

LAT science team member Alice Harding of NASA's Goddard concludes, "We're going to find things that we don't understand. Then we will have to figure out how to deal with it. It will be fun to study the sources we know about, but even more fun to solve the mysteries of the sources we can't explain."



The EGRET instrument on NASA's Compton Gamma-ray Observatory mapped 271 sources. Nearly two thirds of these gamma-ray sources remain unidentified. Credit: EGRET Team

NASA
Science Mission Directorate

GLAST LAUNCH AND OPERATION QUICK FACTS

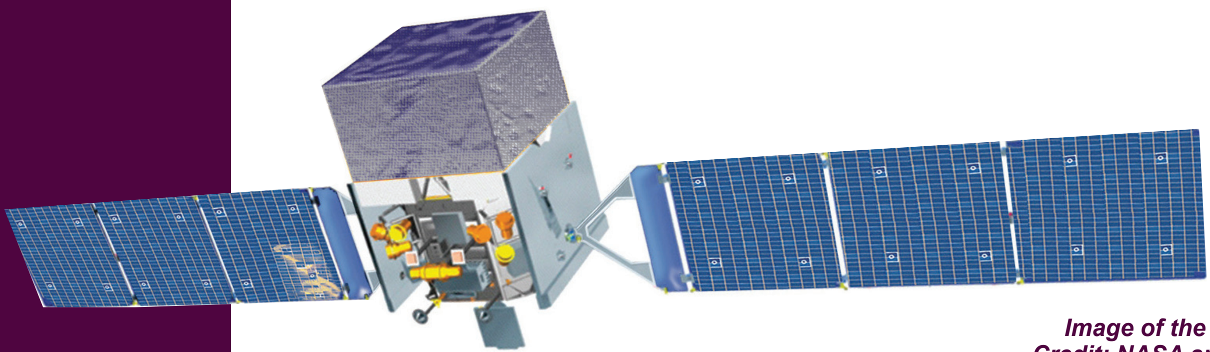


*Image of the GLAST Satellite.
Credit: NASA and Sonoma State University, Aurore Simonnet*

HOW BIG IS THE SPACECRAFT?

It is 9.2 feet (2.8 meters) high by 8.2 feet (2.5 meters) in diameter when stowed, where it is just under the 9-foot diameter allowed in the fairing. GLAST becomes a little bit taller and much wider after it is launched into space, when the Ku-band antenna deploys and the solar arrays are extended.

Key Characteristics
Mass: The GLAST observatory weighs 9,487 lbs (4,303 kg)
Large Area Telescope (LAT) Mass: 6,149 lbs (2,789 kg)
Gamma-Ray Burst Monitor (GBM) Mass: 219 lbs (99.2 kg)
Dimensions of the Spacecraft: 9.2 feet (2.8 meters) high x 8.2 feet (2.5 meters) in diameter when stowed
Power consumption: about 1,500 watts average over an orbit (solar panels supply up to 3,122 watts in sunlight)
Data downlink: 40 megabits per second, multiple contacts per day
Launch Site: Cape Canaveral Air Station, Fla.
Expendable Launch Vehicle: Delta II Heavy launch vehicle, with 9 solid rocket boosters. The solids are actually from the Delta III series (hence the term “heavy”), mounted on a 10 foot fairing and two stages
Launch Date: early 2008

Project Management:
NASA’s Goddard Space Flight Center (GSFC)
Project Scientist: Steve Ritz, GSFC
Project Manager: Kevin Grady, GSFC
LAT Management:
Stanford Linear Accelerator Center (SLAC)
LAT PI: Peter Michelson, Stanford
GBM Management:
NASA’s Marshall Space Flight Center (MSFC)
GBM PI: Charles (Chip) Meegan, MSFC
GBM Co-PI: Jochen Greiner, Max Planck Institute for Extraterrestrial Physics
International Partners:
LAT: France, Italy, Japan, and Sweden
GBM: Germany
GLAST Science Support Center:
NASA’s Goddard Space Flight Center
Lead Education and Outreach:
Lynn Cominsky, Sonoma State University
Spacecraft Contractor:
General Dynamics Advanced Information Systems (AIS)

QUICK FACTS

GLAST INSTRUMENTS

INTRODUCTION

The Gamma-ray Large Area Space Telescope (GLAST) is an international and multi-agency space observatory that will study the cosmos in the photon energy range of 8,000 electronvolts (8 keV) to greater than 300 billion electronvolts (300 GeV). An electronvolt is a unit of energy close to that of visible light, so GLAST will catch photons with energies thousands to hundreds of billions of times greater than those we see with our eyes (1 keV = 1,000 eV, 1 MeV = 1,000,000 eV, 1 GeV = 1,000,000,000 eV).

GLAST carries two instruments: the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The LAT is GLAST's primary instrument, and the GBM is the complementary instrument.

REQUIREMENTS FOR THE LAT AND GBM

Based on our knowledge of the gamma-ray sky from previous missions, scientists defined the following requirements for the GLAST instruments:

The Large Area Telescope (LAT)

1. Because the sky at gamma-ray energies has so many variable sources, the LAT must have a large field of view, over 2 steradians (one-fifth of the entire sky).
2. To identify and study sources accurately, the LAT must be able to measure the locations of bright sources to within 1 arcminute (about 1/30 of the diameter of the full Moon).
3. The study of gamma rays covers a broad energy range, so the LAT must catch photons with energies from 30 MeV to greater than 300 GeV. In particular, the LAT will have high sensitivity above 10 GeV, because almost nothing is known about cosmic objects at these energies.
4. Since gamma-ray bursts can release a torrent of gamma rays within a fraction of a second, the LAT must be able to measure gamma rays over short time intervals.
5. Because scientists need long observations to understand many types of sources, the LAT should be able to operate for many years without degradation.
6. Because of the high flux of cosmic rays, which can mask the much smaller flux of gamma rays, the LAT must be able to reject 99.999% of signals generated by cosmic rays.

The GLAST Burst Monitor (GBM)

1. Gamma-ray bursts (GRBs) come from random directions of the sky, so the GBM must watch as much of the entire sky as possible at all times.
2. To gain the most information about GRBs, the GBM should be able to measure photon energies over a wide range, down to 8 keV and up to energies that overlap the LAT energy range.
3. Since GRBs last from mere microseconds to thousands of seconds, the GBM must be able to detect GRBs over a wide range of timescales.

THE INSTRUMENTS

Large Area Telescope (LAT)

The LAT has four subsystems that work together to detect gamma rays and to reject signals from the intense bombardment of cosmic rays. For every gamma ray that enters the LAT, it will have to filter out 100,000 to one million cosmic rays, charged particles that resemble the particles produced by gamma rays. The four main subsystems are:

- Tracker
- Calorimeter
- Anticoincidence Detector
- Data Acquisition System

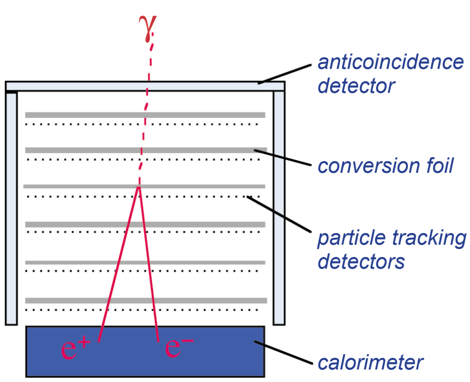
The LAT (silver box at the top) was integrated on the spacecraft at General Dynamics Advanced Information Systems in December 2006. Credit: NASA/General Dynamics Advanced Information Systems

With its very large field of view, the LAT sees about 20% of the sky at any given moment. In sky-survey mode, which is the primary observing mode, the LAT will cover the entire sky every three hours. The observatory can also be pointed at targets of opportunity, and can slew autonomously when either instrument detects sufficiently bright gamma-ray bursts (GRBs). The LAT is at least 30 times more sensitive than any previous gamma-ray instrument flown in space, and will detect thousands of new sources during GLAST's five-year primary mission.

The LAT was assembled at the Stanford Linear Accelerator Center (SLAC), but with substantial hardware contributions from partners in France, Italy, Japan, Sweden, and the U.S. SLAC also manages the collaboration. The Principal Investigator is Peter Michelson of Stanford University/ SLAC.

How the LAT Detects Gamma Rays and Rejects Cosmic Rays

1. A gamma ray enters the LAT. It first passes through the Anticoincidence Detector without producing a signal.
2. The gamma ray interacts in one of 16 thin tungsten sheets. This interaction converts the gamma ray into an electron and a positron via pair production (governed by Einstein's equation $E=mc^2$).
3. The Tracker uses silicon strips to measure the paths of the electron and positron, allowing the LAT to determine the arrival direction of the gamma ray.
4. The electron and positron enter the Calorimeter, which measures the energies of the particles, and therefore the energy of the original gamma ray.

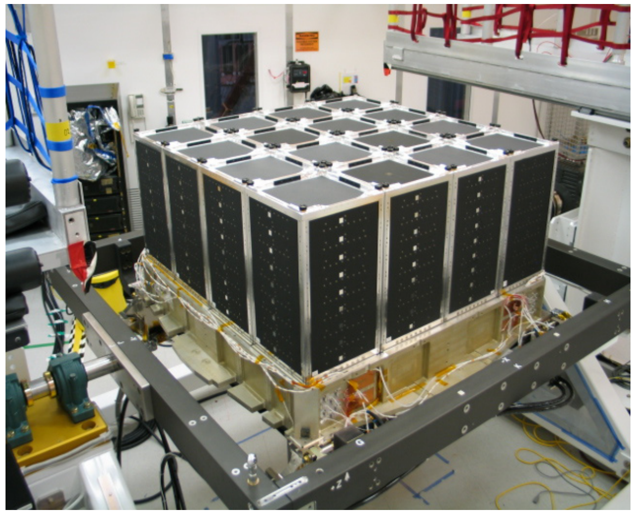


Credit: NASA

5. Unwanted cosmic-ray particles produce a signal in the Anticoincidence Detector, which tells the Data Acquisition System to reject the signal. The Anticoincidence Detector rejects 99.97% of unwanted signals produced by cosmic rays that enter the LAT.
6. Software in the LAT Data Acquisition System also rejects, based on arrival direction, unwanted gamma rays that originate in Earth's atmosphere.

INSTRUMENTS

Components of the LAT


The LAT has 16 towers of particle detectors, seen here before the installation of the Anticoincidence Detector. Each tower contains a Tracker module and a Calorimeter module. The Data Acquisition System is located underneath the towers.
Credit: SLAC

Tracker

The Tracker consists of a four-by-four array of tower modules. Each tower module consists of layers of silicon-strip particle tracking detectors interleaved with thin tungsten converter foils. The silicon-strip detectors precisely measure the paths of the electron and positron produced from the initial gamma ray. The pair-conversion signature is also used to help reject the much larger background of cosmic rays.

Calorimeter

The Calorimeter measures the energy of a particle when it is totally absorbed. The LAT Calorimeter is made of a material called cesium iodide that produces flashes of light whose intensity is proportional to the energies of the incoming particle. The Calorimeter also helps to reject cosmic rays, since their pattern of energy deposition is different from that of gamma rays.

Anticoincidence Detector (ACD)

The Anticoincidence Detector is the first line of defense against cosmic rays. It consists of specially formulated plastic tiles that produce flashes of light when hit by charged-particle cosmic rays (but not by gamma rays, which are electronically neutral). The ACD forms a “hat” that fits over the tracker.

Data Acquisition System (DAQ)

The Data Acquisition System is the brain behind the LAT. It collects information from the Tracker, the Calorimeter, and the Anticoincidence Detector and makes the initial distinction between unwanted signals from cosmic rays and real gamma-ray signals to decide which of the signals should be relayed to the ground. This system also does an on-board search for gamma-ray bursts. The DAQ consists of specialized electronics and microprocessors.

GLAST Burst Monitor (GBM)

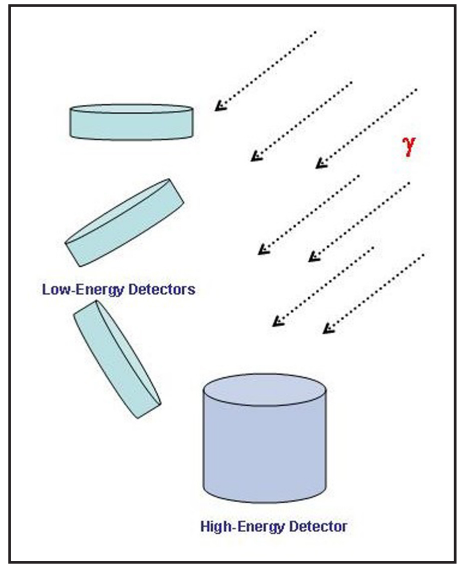
The GBM consists of 12 detectors made of sodium iodide for catching X rays and low-energy gamma rays, and two detectors made of bismuth germanate for high-energy gamma rays. Together, they detect cover X rays and gamma rays in the energy range between 8 keV to 30 MeV, overlapping with the LAT’s lower-energy limit. The GBM detectors will view the entire sky not occulted by Earth, and are expected to pick up about 200 GRBs per year, as well as solar flares and other transient events. The combination of the GBM and the LAT provides a powerful tool for studying GRBs over a very wide range of energies.

The development of the GBM and analysis of its observational data is a collaborative effort between the National Space Science and Technology Center in the U.S. and the Max Planck Institute for Extraterrestrial Physics (MPE) in Germany. The instrument is managed at NASA’s Marshall Space Flight Center in Huntsville, Alabama. Charles “Chip” Meegan of NASA’s Marshall is the Principal Investigator. In July 2007 Jochen Greiner of Max Planck replaced the now-retired Giselher Lichti as Co-P.I.

How the GBM Detects Gamma-Ray Bursts

1 An X ray or low-energy gamma ray from deep space enters one of the 12 GBM low-energy detectors, which are flat disks made of a sodium-iodide material that produces a faint flash of light when struck. A photomultiplier tube detects the flash. 2. The 12 detectors are located on opposite sides of the GLAST satellite, so they face different directions in the sky.

3. When gamma rays from a gamma-ray burst reach the GBM, the disk facing the burst will detect more gamma rays than the others.
4. By comparing the rate of signals from four or more detectors, the GBM can traingulate the arrival direction of the burst to within several degrees.
5. Two high-energy detectors made of bismuth germante pick up higher-energy gamma rays and measure their energies in much the same way as the low-energy detectors.



Credit: NASA / David Thompson

Components of the GBM

Low-Energy Detectors

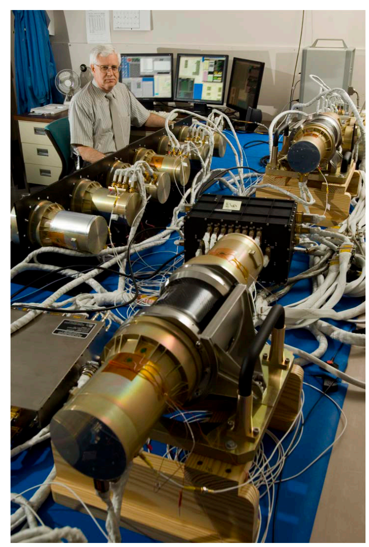
The low-energy sodium iodide detectors detect X rays with about 8 keV of energy up to gamma rays with about 1 MeV. They provide the locations of gamma-ray bursts to within several degrees, and they overlap in energy with other missions that detect GRBs, such as NASA's Swift satellite. The low-energy detectors are mounted in four banks consisting of three detectors each. The 12 detectors are oriented in various directions so they face different parts of the sky. The GBM uses the signals from the low-energy detectors to detect burst locations.

High-Energy Detectors

The high-energy detectors are made of bismuth germanate, which is sometimes abbreviated BGO because germanate is a germanium oxide. They cover the energy range from about 150 keV to about 30 MeV, providing a good overlap with the low-energy detectors at the bottom end of the gamma-ray energy range, and with the LAT at the high end. Bismuth germanate is a high-density material that provides better sensitivity at high energies. The two high-energy detectors are positioned on opposite sides of the spacecraft, providing nearly full sky coverage.

Data Processing Unit

The electronics and microprocessors in the data processing unit receive and analyze the data from the low-energy detectors and high-energy detectors. It detects GRBs, determines their energies and arrival directions, and sends data to the GLAST spacecraft for transmission to the ground.



GLAST Burst Monitor Principal Investigator Charles "Chip" Meegan, an astrophysicist at NASA's Marshall Space Flight Center in Huntsville, Ala., tests the GLAST Burst Monitor. Credit: NASA/MSFC/ D. Higginbotham

GLAST WEB SITES

Here are links to GLAST web pages at various institutions.

USA

NASA's GLAST mission
http://www.nasa.gov/glast
NASA's Goddard Space Flight Center
http://glast.gsfc.nasa.gov/
Astrophysics Science Division at NASA's Goddard Space Flight Center
http://astrophysics.gsfc.nasa.gov
Sonoma State University
http://glast.sonoma.edu/
Space Sciences Laboratory at NASA's Marshall Space Flight Center (GBM Site)
http://gammaray.msfc.nasa.gov/gbm
Stanford Linear Accelerator Center (LAT Site)
http://glast.slac.stanford.edu/
Stanford University (LAT Site)
http://glast.stanford.edu
University of California, Santa Cruz
http://scipp.ucsc.edu/groups/glast/
University of Washington
http://glast.phys.washington.edu/
U.S. Naval Research Laboratory
http://heseweb.nrl.navy.mil/glast/index.html

FRANCE

CEA Saclay
http://www-dapnia.cea.fr/Sap/Activites/Projets/GLAST/index.html
École Polytechnique
http://polywww.in2p3.fr/activites/physique/glast/
IN2P3 GLAST Web site
http://GLAST.IN2P3.FR
Laboratoire de Physique Theorique & Astroparticules (LPTA Monpellier), France
http://www.lpta.univ-montp2.fr/rubrique.php3?id_rubrique=87

ITALY (sites in English)

INFN Bari University
http://www.ba.infn.it/~glast/
INFN Padova
http://sirad.pd.infn.it/glast/index.html
INFN Perugia
http://glastweb.pg.infn.it/
INFN Pisa
http://glast.pi.infn.it/
INFN Rome
http://www.roma2.infn.it/research/comm2/glast/
Udine
http://www.fisica.uniud.it/~glast/udine.html

JAPAN

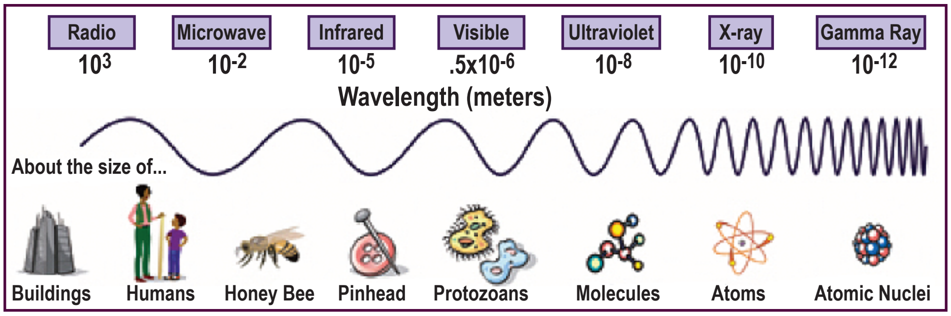
Hiroshima University
http://www-heaf.hepl.hiroshima-u.ac.jp/glast/glast-e.html

SWEDEN

http://www.particle.kth.se/~tomiy/glast-sweden/glast.html

ELECTROMAGNETIC SPECTRUM BASICS

To be able to understand how GLAST works, you need to understand the electromagnetic spectrum.



Credit: NASA / Ruth Jennings

("WHAT ARE GAMMA RAYS")

What we call "light" is actually just a tiny fraction of the broad range of radiation on the electromagnetic radiation spectrum. The entire span stretches from very-low-energy radio waves through microwaves, infrared light, visible light, ultraviolet light, X rays, and finally to very-high-energy gamma rays. The processes producing photons (single particles of electromagnetic radiation) of each type of radiation differ, as do their energy, but all of the different forms of radiation are still just part of the electromagnetic spectrum. The only real difference between a gamma-ray photon and a visible-light photon is the energy. Gamma rays can have over a billion times the energy of the type of light visible to our eyes.

In fact, gamma rays are so energetic that they are harmful to life on Earth. Luckily, Earth's atmosphere absorbs gamma rays, preventing them from affecting life on the ground. But this poses a problem if you want to observe the Universe in gamma-ray light. The very atmosphere that protects us from gamma rays prevents us from directly observing them from the ground. Astronomical observations of gamma-ray sources in the GLAST energy range are therefore done with high-altitude balloons or satellites, above the protective blanket of Earth's atmosphere.

The high energy of gamma rays poses another problem: they can pass right through any lens or mirror, making it very difficult to focus them in a telescope. Astronomical observations, therefore, must rely on different technologies to view the gamma-ray universe. Scientists must make use of methods developed by particle physicists, who have long understood techniques for measuring high-energy particles. GLAST's specialized astronomical instruments will therefore employ detectors used and perfected by physicists interested in the interactions of subatomic particles.

EDUCATION AND PUBLIC OUTREACH PRODUCTS

Education and Public Outreach Products for GLAST from Sonoma State University

Online Activities can be found at: http://glast.sonoma.edu/teachers/online.html
Following are a list of activities and descriptions of them with the direct links to them:

- GLAST Large Area Tracker Simulator - See what happens when gamma rays and particles enter the GLAST Large Area Telescope at different angles and with different energies: http://www2.slac.stanford.edu/vvc/glastlat/lat_simulator.html
- Space Mysteries - Can you solve the mysteries? Two space mysteries featuring GLAST science: Found at: http://mystery.sonoma.edu/

The GLAST Educator Ambassadors program: http://glast.sonoma.edu/ambassadors/index.html GLAST supports 10 Educator Ambassadors that help develop, test, and disseminate educational materials based on science from NASA's Astrophysics Division of the Science Mission Directorate. There are now 16 Educator Ambassadors in this program.

- Meet the Educator Ambassadors - the people, their biographies, and their missions: http://glast.sonoma.edu/ambassadors/ambassadors.html
- Educator Ambassadors in the News - recent news articles featuring the Educator Ambassadors: http://epo.sonoma.edu/ambassadors/ambassador_news.html
- Upcoming Events - a list of workshops being conducted by the Educator Ambassadors: http://epo.sonoma.edu/ambassadors/events.php

The Global Telescope Network - Use real astronomical data in your classroom: http://gtn.sonoma.edu/public/

GLAST Classroom Materials: http://glast.sonoma.edu/teachers/teachers.html

Printed Materials:
- Black Hole Resource Area: http://glast.sonoma.edu/teachers/blackholes/index.html
- Supernova Educator Guide - The GLAST and XMM-Newton E/PO programs have developed a set of formal activities and background materials about supernovae. This is being jointly developed for GLAST and XMM-Newton. Found at: http://xmm.sonoma.edu/edu/supernova/index.html
- TOPS Learning Systems has developed a three-booklet series of activities based on the math and science of the GLAST mission. In the TOPS tradition, each booklet has activities which use simple, inexpensive household materials (such as coins, paper plates, thread spools, etc.) in clever ways. http://topscience.org/
- Download "Far Out Math!" PDF (11.5Mb): http://glast.sonoma.edu/teachers/topsmod1.pdf
- Presentation: TOPS Far Out Math! http://glast.sonoma.edu/teachers/topsmod1.pdf
- Booklet 2, "Scale the Universe": The size and scale of the Universe are among the most difficult concepts to understand. This booklet gently takes students through the orders-of-magnitude of the Universe starting with the familiar human scale, then going down to the infinitesimal and out to the astronomical.
- Download "Scale the Universe" PDF (3.7Mb): http://glast.sonoma.edu/teachers/scale_universe.pdf
- Booklet 3, "Pi in the Sky": These activities teach about radians and degree, angles, parallax, and apparent sizes of objects. Students will measure the apparent sizes of objects at various distances and learn about how we can measure the sizes of distant objects.
  Download "Pi in the Sky" PDF (20Mb) : http://glast.sonoma.edu/teachers/pi_in_the_sky.pdf
  Presentation: TOPS Scale the Universe and Pi in the Sky

Active Galaxy Education Unit

The GLAST E/PO team has developed a set of three activities to teach students about active galaxies. All three activities are aligned with the national science and mathematics standards. A beautiful poster illustrating an Active Galaxy features one of the three activities on the reverse side.

- Active Galaxies Poster: http://glast.sonoma.edu/images/agn.html
- Active Galaxies Poster without the text: http://glast.sonoma.edu/images/agnnotext.html
- Educator Guide: Download PDF (3.36 Mb): http://glast.sonoma.edu/teachers/agn/agnacti027.pdf
- Educator Guide (HTML Version): http://glast.sonoma.edu/teachers/agn/index.html
- Active Galaxy Pop-up Book - This short, innovative book for ages 8-12 has three separate activities, including a popup 3D galaxy showing its features, the “Tasty Active Galaxy” activity where kids can make their own edible black hole, and a whimsical story about supermassive black holes called “How the Galaxy Got Its Jets”. Although designed for younger children, it can be enjoyed by people of all ages (especially eating the black hole): http://glast.sonoma.edu/teachers/popup.html

Miscellaneous GLAST Education Products

- GLAST Mission Poster - features an artist’s drawing of the GLAST satellite in orbit: http://glast.sonoma.edu/images/glaunchflp03.html
- The GLAST Cube - images and text from the GLAST “magic cube”: http://glast.sonoma.edu/resources/cubeimages/cube.html
- GLAST Public Brochure: http://glast.sonoma.edu/resources/brochure/glastbroch04.pdf
- GLAST Race Trading Card Game — Who will be the first to build, launch and make observations with GLAST? http://glast.sonoma.edu/teachers/race.html
- GLAST Sticker - Features artist’s interpretation of an active galaxy as well as an image of the satellite: http://glast.sonoma.edu/resources/sticker/glast_sticker.html

Additional GLAST Education and Public Outreach Efforts at UC Santa Cruz:

- The BALLOON Program: http://scipp.ucsc.edu/outreach/ballon.html
- SCIPP Tesla Coil Show: http://scipp.ucsc.edu/outreach/tesla/teslacoil/index.html

- GLAST on MYSPACE.COM: http://www.myspace.com/GLAST

GLAST SCIENCE GLOSSARY

Source: http://glast.sonoma.edu/science/gru/glossary.html

Accretion — The process whereby a compact object such as a black hole or neutron star captures matter from a normal star or diffuse cloud.
Active galactic nuclei (AGN) — The central region of some galaxies that appears as an extremely luminous point-like source of radiation. They are powered by supermassive black holes accreting nearby matter.
Annihilation — The process whereby a particle and its antimatter counterpart interact, converting their mass into energy according to Einstein's famous formula $E = mc^2$. For example, the annihilation of an electron and positron results in the emission of two gamma-ray photons, each with an energy of 511 keV.
Anticoincidence Detector — A system on a gamma-ray observatory that triggers when it detects an incoming charged particle (cosmic ray) so that the telescope will not mistake it for a gamma ray.
Antimatter — A form of matter identical to atomic matter, but with the opposite electric charge.
Arcminute — One-sixtieth of a degree on the sky. Like latitude and longitude on Earth's surface, we measure positions on the sky in angles. A semicircle that extends up across the sky from the eastern horizon to the western horizon is 180 degrees. One degree, therefore, is not a very big angle. An arcminute is an even smaller angle, 1/60 as large as a degree. The Moon and Sun are each about half a degree across, or about 30 arcminutes. If you take a sharp pencil and hold it at arm's length, then the point of that pencil as seen from your eye is about 3 arcminutes across.
Astronomy — The scientific study of the Universe and objects beyond Earth, especially the positions, dimensions, distribution, motion, composition, energy, and evolution of celestial bodies and phenomena.
Astrophysics — A combination of physics and astronomy that deals principally with the physical processes of celestial bodies and phenomena.
Atmospheric Cherenkov Telescopes (ACTs) — Ground-based telescopes that indirectly detect very-high-energy gamma rays from space. These gamma rays interact with atoms in Earth's atmosphere, producing Cherenkov Light.
Atom — The smallest unit of an element which keeps the element's characteristics. An atom consists of one or more protons and neutrons (except for hydrogen, which may have no neutrons) in a nucleus, with one or more electrons outside the nucleus.
BATSE — The Burst and Transient Source Experiment on board the Compton Gamma-ray Observatory. BATSE made all-sky observations of gamma-ray bursts and flares, as well as observing many other objects between 10 keV and 5 MeV.
Big Bang — A theory of cosmology in which the Universe once existed in a hot, dense state, and has been expanding ever since.
Binary stars — Two stars that orbit around a common center of mass.
Black hole — An object with gravity so strong that nothing, not even light, can escape.
Blazar — A type of active galactic nucleus (AGN) that often appears as a point-like source of bright, highly variable radiation. Astronomers think blazars are AGN that have a jet of matter and radiation pointed directly at Earth.
Calorimeter — A detector that absorbs particles and photons, producing an electrical signal proportional to the total incident energy. It can be used to measure a gamma ray's energy.
Cherenkov light — Blue light emitted when particles travel through a medium faster than light travels through that medium.
Compton Gamma-ray Observatory (CGRO) — A NASA gamma-ray mission that was launched in April 1991, and which re-entered Earth's atmosphere in June 2000. CGRO had four experiments: BATSE, OSSE, COMPTEL, and EGRET, which together spanned the energy range 10 keV to 30 GeV.
COMPTEL — The Imaging Compton Telescope experiment on board the Compton Gamma-ray Observatory. COMPTEL detected gamma rays in the energy range 100 keV to 30 MeV.

Converter — Material in which the pair-production process takes place. Due to conservation of momentum and energy, pair production cannot take place in empty space.
Cosmic rays – Elementary particles or atomic nuclei that travel through interstellar space at speeds approaching that of light.
Cosmology — The study of the origin, structure, and evolution of the Universe.
Dark matter — A non-luminous gravitational component of the Universe invoked to explain the internal motions of galaxies and the motions of galaxies within clusters of galaxies.
Degree — A unit of angular size. One degree is 1/360 of a full circle, or, conversely, there are 360 degrees in a circle.
Density — The ratio between the mass of an object and its volume.
Diffuse galactic emission — Non-point-source gamma-ray emission from the plane of our Milky Way Galaxy. Mostly due to interactions of cosmic rays with interstellar material.
EGRET — Energetic Gamma Ray Experiment Telescope on board the Compton Gamma-ray Observatory. It operated from 30 MeV to 30 GeV.
Electromagnetic spectrum — All the different wavelengths of light, which is also called electromagnetic radiation. Only a small portion of this spectrum is visible to the human eye. From lowest to highest energy, the broad energy bands within this spectrum are: radio, microwave, infrared, visible, ultraviolet, X rays, and gamma rays.
Electron — An elementary particle with a single negative charge, and a mass of about 511 keV.
Electronvolt (eV) — A unit of energy, sufficient to excite atoms to emit visible light. (1 keV=1,000 eV, 1 MeV=1,000 keV, 1 GeV=1,000 MeV).
Extragalactic — Outside of, or beyond, our own Milky Way Galaxy.
Flux — A measurement of the brightness of a source.
Frequency — A property of a wave that describes how many wave patterns or cycles pass by in a period of time. Frequency is often measured in Hertz (Hz), where a wave with a frequency of 1 Hz will pass by at 1 cycle per second.
Galaxy — A component of our Universe made up of gas, a large number (usually more than a million) of stars, and dark matter. A galaxy is held together by gravity.
Gamma ray — A photon more energetic than an X ray (more than about 50 keV). Gamma rays are created from nuclear reactions or particle accelerations. Gamma rays are the most energetic photons of the electromagnetic spectrum.
Gamma-ray background — A diffuse glow of gamma rays seen in all directions. Most of the background is probably due to unresolved blazars and other AGN.
Gamma-ray burst (GRB) — A brief but intense torrent of gamma-ray emission from a point source in deep space. Astronomers think most GRBs are produced by exploding stars.
General theory of relativity — Einstein's theory of gravity that unites special relativity, Newton's laws of gravitation, and the insight that gravitational acceleration can be described by the curvature of space and time.
GLAST — Gamma-ray Large Area Space Telescope.
GLAST Burst Monitor (GBM) — The instrument on GLAST that is specifically designed to detect gamma-ray bursts.
Gravity — The attractive force of an object with mass on another object. The gravitational force between two objects depends on their masses and the distance between them.
Hawking radiation — A theoretical faint glow of particles and radiation from a black hole, predicted by Stephen Hawking as a result of quantum-mechanical effects.
Infrared — The region of the electromagnetic spectrum with wavelengths in the range of 2.5×10^{-6} meters to 7×10^{-7} meters. Infrared photons are between visible-light photons and microwaves in the electromagnetic spectrum.
Interstellar — Material or space between the stars.
Ion — An atom or molecule that has lost or gained one or more electrons and has become electrically charged as a result.
Ionization — The process by which ions are produced, typically occurring by collisions with atoms or electrons, or by interaction with electromagnetic radiation.
Jet — A collimated stream of relativistic particles and photons which flows from a central source (often a black hole).

Kelvin (K) — A temperature scale (named after Lord Kelvin) that measures an object's temperature above absolute zero, the theoretical coldest possible temperature. The temperature in Kelvins can be converted to Celsius by the equation K = 273 + C and to Fahrenheit by K = 273 + 5/9 * (F - 32).
Kilogram (kg) — A unit of mass. One kilogram is defined as the mass of one liter (1,000 cubic centimeters) of water at 277 Kelvin. 1 kg = 2.2046 pounds.
Large Area Telescope (LAT) — The primary science instrument on GLAST.
Light — Generally used to mean electromagnetic radiation that is visible to the human eye. Sometimes used to mean all wavelengths of electromagnetic radiation.
Light-year — The distance light travels in 1 year: 9.5 trillion kilometers or 5.9 trillion miles.
Luminosity — The rate at which a star or other object emits energy, usually in the form of electromagnetic radiation.
Magnetar — A neutron star with an extraordinarily powerful magnetic field.
Magnetic field — The region of space around a magnetic body or a current-carrying body where objects can be affected by the magnetic forces due to the body or current.
Magnetosphere — The immediate region around a body with a magnetic field where particle behavior is controlled by that field.
Mass — A measure of the total amount of material contained in a body.
Meter (m) — The fundamental international unit of length, defined as the length of the path traveled by light in vacuum during a period of 1/299,792,458 second. One meter is approximately 39.4 inches.
Microwave — The region of the electromagnetic spectrum with wavelengths in the range of 2.5 x 10^{-6} meters to 10^{-4} meters. Microwave photons are between infrared and radio in the electromagnetic spectrum.
Milky Way — The name of our own Galaxy, which contains a flattened disk of stars about 100,000 light-years across, along with star clusters, interstellar gas and dust, and vast amounts of dark matter.
NASA — The National Aeronautics and Space Administration, founded in 1958. www.nasa.gov
Nebula — A diffuse cloud of interstellar gas and dust.
Neutron — A particle commonly found in the nucleus of an atom with approximately the mass of a proton, but with zero electrical charge.
Neutron star — An extremely dense core of a dead star that exploded as a supernovae. Neutron stars have diameters of about 20 kilometers and masses of about 1.5 times that of our Sun. A neutron star internally supports itself against gravity by pressure from the strong nuclear force between neutrons.
Nucleus (plural: nuclei) — The positively charged central portion of an atom that comprises nearly all of the atomic mass and that consists of protons and (except for the simplest form of hydrogen) neutrons. In general, the central point, group, or mass about which gathering, concentration, or accretion takes place.
Occam's Razor — A scientific principle that states that the simplest explanation for a phenomenon is usually the most desirable explanation.
Orbit — The path of an object that is moving around a second object or point under the influence of gravity.
OSSE — Oriented Scintillation Spectrometer Experiment on board the Compton Gamma-ray Observatory (operated between 50 keV and 10 MeV).
Pair production — A physical process in which a gamma-ray photon transforms itself into a particle and its antimatter counterpart.
Parallax — The apparent motion of a relatively close object compared to a more distant background as the location of the observer changes. Astronomically, it is half the angle which a star appears to move as Earth moves from one side of the Sun to the other.
Particle accelerator — Any machine or natural object that can accelerate charged particles, such as electrons, positrons, or protons to speeds approaching that of light.
Photomultiplier tube — A device that produces electrical signals from faint pulses of light, using the photoelectric effect to produce a few electrons from incident light, then multiplying the number of electrons by a cascade process.

Photon — The fundamental “particle” of light. The energy of a photon is proportional to its frequency.
Photon splitting — A physical process in which a very-high-energy gamma-ray photon can borrow energy from an external source, such as a very strong magnetic field, and split into two lower-energy photons.
Pion — An unstable nuclear particle with a rest mass between that of an electron and a proton. Also known as the pi meson.
Positron — The antimatter counterpart of the electron, essentially an electron with a positive charge.
Primordial black hole — A black hole that formed in the very early Universe from a dense concentration of matter. Primordial black holes have never been observed.
Proton — A positively charged particle commonly found in the nucleus of an atom.
Pulsar — A type of neutron star with a beam of emission that sweeps around as the star rotates.
Pulsar wind nebula — A cloud created from gas and particles blown off a neutron star.
Quantum fluctuations — A short-lived change in the state of empty space due to quantum mechanics. Quantum fluctuations can often involve the rapid production and annihilation of virtual pairs of particles and their antimatter counterparts.
Quantum gravity — Theories that attempt to merge Einstein’s general theory of relativity and quantum mechanics.
Quantum mechanics — The branch of physics dealing with the interactions of matter, energy, and space at tiny scales.
Quasar — A type of active galactic nucleus with a core that is extremely luminous in visible light and sometimes other wavelengths as well.
Radiation — The process in which energy is emitted as electromagnetic waves, or the energy itself.
Radio — The region of the electromagnetic spectrum with wavelengths longer than 10^{-4} meters. Radio photons have the lowest energies and longest wavelengths in the electromagnetic spectrum.
Radio galaxy — A galaxy with strong radio emission, usually powered by an active galactic nucleus.
Redshift — The shift of spectral lines to longer wavelengths either due to the motion of the source away from the observer, the expansion of the Universe, or very strong gravity.
Resolution — The size of the smallest detail visible in an image. Low resolution shows only large features, high resolution shows many small details.
Satellite — A natural or artificial body that revolves around a more massive body. For example, the Moon is a satellite of Earth.
Scintillation — The emission of light that occurs when electrons or positrons excite a substance in a transparent material they are passing through.
Seyfert galaxy — A type of active galactic nucleus that is very luminous, but not as luminous as a quasar or blazar.
Shock waves — A compressional wave triggered by an explosion or energetic event.
Silicon-strip detectors (SSD) — Detectors made of tiny strips of silicon, which create voltage pulses when traversed by high-energy charged particles, such as protons, electrons, or positrons.
Solar flare — A burst-like emission of radiation and particles from a magnetic disturbance on the Sun.
Solar mass — A unit of mass equivalent to the mass of the Sun: 1 solar mass = 2×10^{30} kilograms.
Special theory of relativity — Einstein’s theory of motion that relates mass and energy, and that states that no information can travel faster than the speed of light in a vacuum.
Spectrum (plural: spectra) — A plot of the intensity of light as a function of frequencies; the distribution of wavelengths and frequencies.
Speed of light (in a vacuum, c) — The speed at which electromagnetic radiation propagates in a vacuum; it is defined as 299,792,458 meters per second (186,282.4 miles per second). Einstein’s special theory of relativity implies that no information can travel faster than the speed of light.

Standard Model of particle physics — A highly successful theory that describes three of the four known fundamental forces of nature and the elementary particles that make up all matter.
Star — A large ball of gas that creates and emits its own radiation through the process of nuclear fusion, or the core of star that once created and emitted its own radiation through fusion.
Starburst galaxy — A galaxy undergoing an intense round of star formation.
Strong nuclear force — A short-range but powerful nuclear force that operates within an atomic nucleus to hold protons together despite their positive electric charges.
Subatomic particles — Particles that are smaller than an atom. Examples include the electron, proton, and neutron.
Superluminal motion — An optical illusion in which material appears to be traveling faster than the speed of light.
Supernova — An extremely energetic and life-ending explosion of a star.
Supernova remnant — The outwardly expanding outer portions of a star that exploded as a supernova and the expanding gaseous shell swept up by a supernova shock wave.
Supersymmetry — An extension of the Standard Model of particle physics, supersymmetry hypothesizes the existence of a complete set of additional particles which complement those that are known to exist. Thus far, no supersymmetric particles have been detected. In some theories, the least massive supersymmetric particle (often called a WIMP) could be a good candidate for dark matter.
Swift — A NASA satellite launched in 2004 that was specifically designed to study gamma-ray bursts.
Tracker — The part of a high-energy gamma-ray detector that is used to determine the trajectory of the incoming gamma-ray. For a silicon-strip detector-based tracker, the trajectories of electron-positron pairs are recorded. These pairs are produced by the converter.
Transient — A source that appears and then disappears, such as a gamma-ray burst.
Ultraviolet — The region of the electromagnetic spectrum with wavelengths in the range of 10^{-9} meters to 4×10^{-7} meters. Ultraviolet photons are between X rays and visible light in the electromagnetic spectrum.
Vacuum — A space largely devoid of matter.
Visible light — The region of the electromagnetic spectrum seen by the human eye, with wavelengths in the range of 4×10^{-7} meters to 7×10^{-7} meters. Visible-light photons are between ultraviolet and infrared.
Wavelength — The distance between the crest (or trough) on a wave and the crest (or trough) in the next cycle.
White dwarf — The exposed core of a relatively low-mass star after it has ejected its atmosphere; it's approximately the size of Earth but with the mass of our Sun.
WIMP — Weakly Interacting Massive Particle; elementary particles predicted by supersymmetry but which have not been observed. WIMPS might comprise some or most of the Universe's dark matter.
X ray — The region of the electromagnetic spectrum with wavelengths in the range of 10^{-12} meters to 10^{-9} meters. X rays are between gamma rays and ultraviolet light in the electromagnetic spectrum.
X-ray binary — A binary star where one of the stars is a collapsed object such as a white dwarf, neutron star, or black hole. The separation between the stars is small enough so that matter is transferred from the normal star to the collapsed star, producing X rays in the process.

GLAST-RELATED ACRONYMS

ACD	The LAT Anticoincidence Detector Subsystem
ACT	Atmospheric Cherenkov Telescope
AGILE	Astro-rivelatore Gamma a Immagini Leggero (Light Astro Gamma Imaging Detector)
AGN	Active Galactic Nuclei
AIS	Advanced Information Systems (General Dynamics)
ASI	Italian Space Agency
BATSE	Burst and Transient Source Experiment on CGRO
BGO	Bismuth Germanate
Bps	Bits per second
C.R.	Cosmic Ray
CAL	The LAT Calorimeter Subsystem
CANGAROO	Collaboration between Australia and Nippon for a Gamma-Ray Observatory in the Outback
CCD	Charge-coupled Device
CEA	Commissariat a l'Energes Atomique
CENBG	Centre d'etudes Nucleaires de Bordeaux Gradignan
CERN	Centre European pour la Recherche Nucleaire or the European Center for Nuclear Research
CGRO	Compton Gamma-ray Observatory
CNRS	Centre National de la Recherche Scientifique
COMPTEL	Compton Telescope on CGRO
COS-B	European Gamma-ray Astronomy Satellite
DAPNIA	Departement d'Astrophysique, de physique des Particules, de physique Nucleaire et de L'Instrumentation Associee
DAQ	Data Acquisition System
DESY	Deutsches Electron-Synchrotron
DOE	Department of Energy
EDAQ	the LAT Electronics, Data Acquisition and Flight Software Subsystem
EGRET	Energetic Gamma Ray Experiment Telescope on CGRO
EPO	Education and Public Outreach
FOV	Field of View
GBM	GLAST Burst Monitor
Gbps	Gigabits per second
GCN	Gamma-ray Burst Coordinate Network
GeV	Giga (billion) electronvolts
GIOC	GBM Instrument Operations Center
GITD	GLAST Instrument Technology Development
GLAST	Gamma-ray Large Area Space Telescope
GRB	Gamma-ray Burst
GRO	Gamma-ray Observatory
GSFC	NASA's Goddard Space Flight Center
GSI	Gesellschaft für Schwerionenforschung or the Society for Heavy Ion Research
HE	High Energy
HEAO	High Energy Astrophysics Observatory
HEASARC	High Energy Astrophysics Science Archive Research Center
HEPL	W.W. Hansen Experimental Physics Laboratory at Stanford University
H.E.S.S.	High Energy Stereoscopic System
HETE-2	High Energy Transient Explorer
IAU	International Astronomical Union
IDS	Interdisciplinary Scientist
IN2P3	Institut National de Physique Nucleaire et de Physique des Particules
INFN	Istituto Nazionale Di Fisica Nucleare (Italy)

INTEGRAL	International Gamma-Ray Astrophysics Laboratory (European Space Agency)
IOC	Instrument Operations Center
ISAS	Institute for Space and Astronautical Science, Japan
JGC	Japanese GLAST Collaboration
Kbps	Kilobits per second
KEK	National Laboratory for High Energy Physics, Japan
KeV	Kilo (thousand) electronvolts
kg	Kilogram
KSC	NASA's Kennedy Space Center
KTH	Royal Institute of Technology, Sweden
LAT	GLAST Large Area Telescope
LEO	Low Earth Orbit
LHC	Large Hadron Collider
LIOC	LAT Instrument Operations Center
LOF	LAT Operations Facility
MAGIC	Major Atmospheric Gamma Imaging Cherenkov
Mbps	Megabits per second
MeV	Mega (million) electronvolts
MILAGRO	Multiple Institution Los Alamos Gamma Ray Observatory
MOC	Mission Operation Center
MPE	Max Planck Institute for Extraterrestrial Physics
MSFC	NASA's Marshall Space Flight Center
NaI	Sodium Iodide
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCST	Naval Center for Space Technology
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSSTC	National Space Science and Technology Center
OSS	NASA's Office of Space Science
OSSE	Oriented Scintillation Spectrometer Experiment on CGRO
PCC	Laboratoire de Physique Corpusculaire et Cosmologie
PI	Principal Investigator
RXTE	Rossi X-Ray Timing Explorer
SCIPP	Santa Cruz Institute of Particle Physics at UCSC
SGC	Swedish GLAST Collaboration
SLAC	Stanford Linear Accelerator Center
SNR	Supernova Remnant
SSU	Sonoma State University
SU	Stanford University
SU-HEPL	Stanford University Hanson Experimental Physics Laboratory
TeV	Trillion electronvolts
TKR	The LAT Tracker Subsystem
UAH	University of Alabama at Huntsville
UCSC	University of California, Santa Cruz
ULIRG	Ultraluminous Infrared Galaxy
VERITAS	Very Energetic Radiation Imaging Telescope Array System
WIMP	Weakly Interacting Massive Particle

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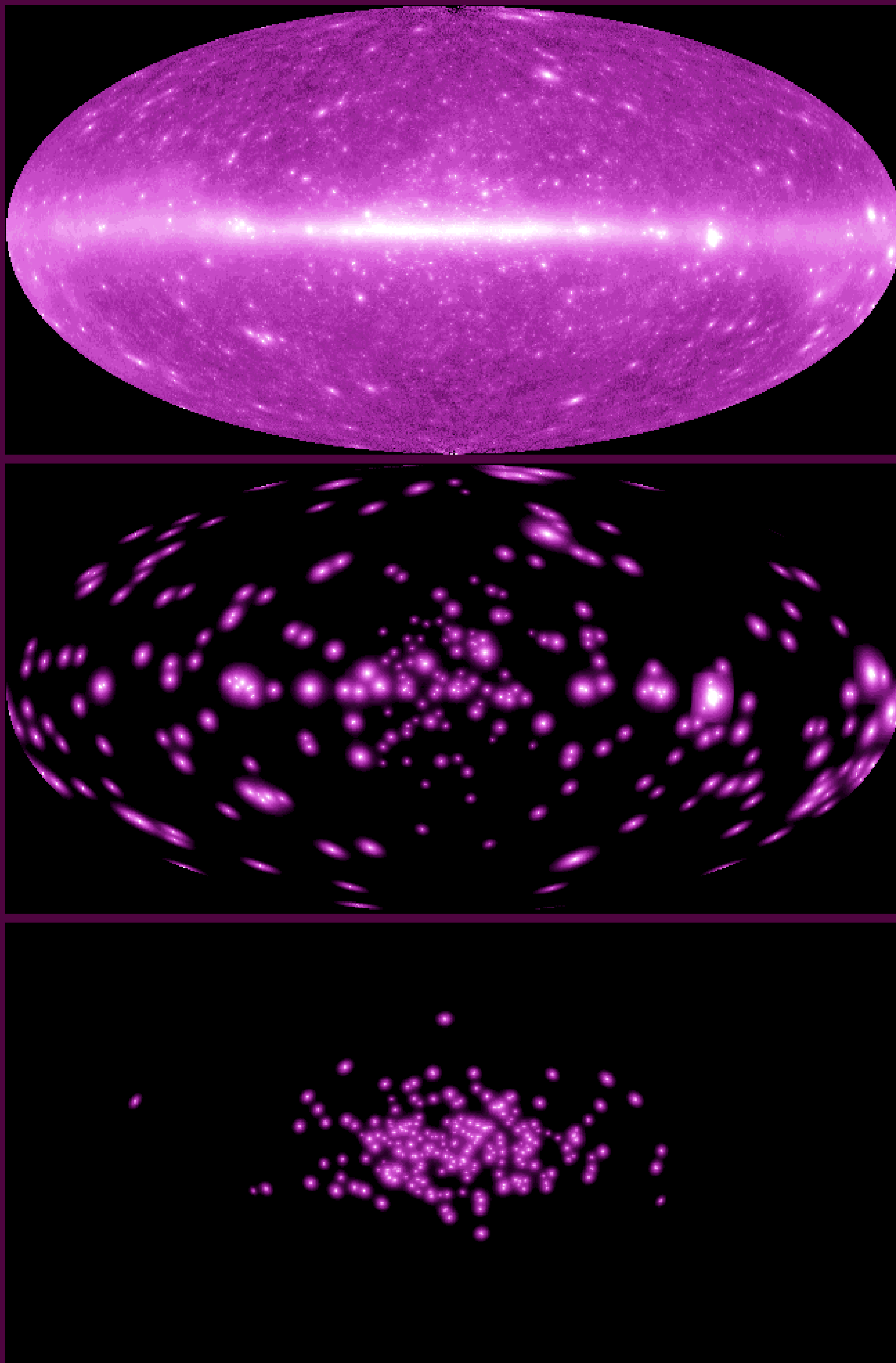

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