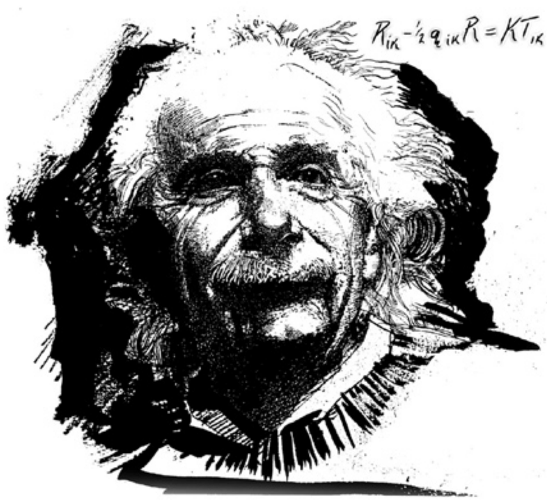
NASA Facts

National Aeronautics and
Space Administration

Marshall Space Flight Center
Huntsville, Alabama 35812

Gravity Probe B

Testing Einstein's Universe



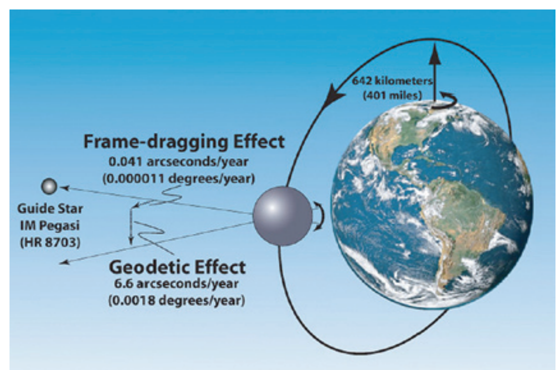
Albert Einstein™ HUJ, Represented by The Roger Richman Agency, Inc., http://www.albert-einstein.net

NASA's Marshall Space Flight Center and Stanford University have developed a sophisticated experiment, Gravity Probe B (GP-B), to test Einstein's general theory of relativity. Einstein's theory predicts that space and time are distorted by the presence of massive objects. Launched on April 20, 2004, the GP-B mission is one of NASA's first to address a question of fundamental physics in the new millennium. NASA fuels discoveries that make the world smarter, healthier and safer.

The Experiment

The GP-B experiment contains the world's most precise gyroscopes. The gyroscopes have been specifically d cause the spin axis orientation of a gyroscope, circling the Earth in a polar orbit, to change by a tiny angle of 6.6 arcseconds (0.0018 degrees) in a year, relative to a distant guide star. The second effect, known as frame-dragging, predicts that massive celestial bodies, such as Earth drag their local spacetime around with them—ever so slightly—as they rotate.

Diagram of the GP-B experiment



Drawing: GP-B Image Archive, Stanford University

The frame-dragging effect should cause the spin axis orientation of an orbiting gyroscope to change in the plane of Earth's rotation (orthogonal to the orbit plane) by a minuscule angle of 0.014 arcseconds (0.000011 degrees) in a year. This effect has never before been measured directly.

Any geodetic and frame-dragging effects are being measured to exceptional precision by GP-B's gyroscopes. These measurements will help shape our understanding of Einstein's theory. If GP-B gives results consistent with general relativity, it will help solidify our understanding of topics like black holes and the evolution of the universe. If, however, the results of the GP-B experiment are inconsistent with Einstein's theory, it will significantly change our scientific perception of the universe.

NASA's Marshall Space Flight Center in Huntsville, Ala., is managing the program. Stanford University in Stanford, Calif., conceived the experiment and is NASA's prime contractor for the mission. Stanford is responsible for the design and integration of the science instrument, payload and spacecraft as well as conducting mission operations and data analysis.

The GP-B Telescope

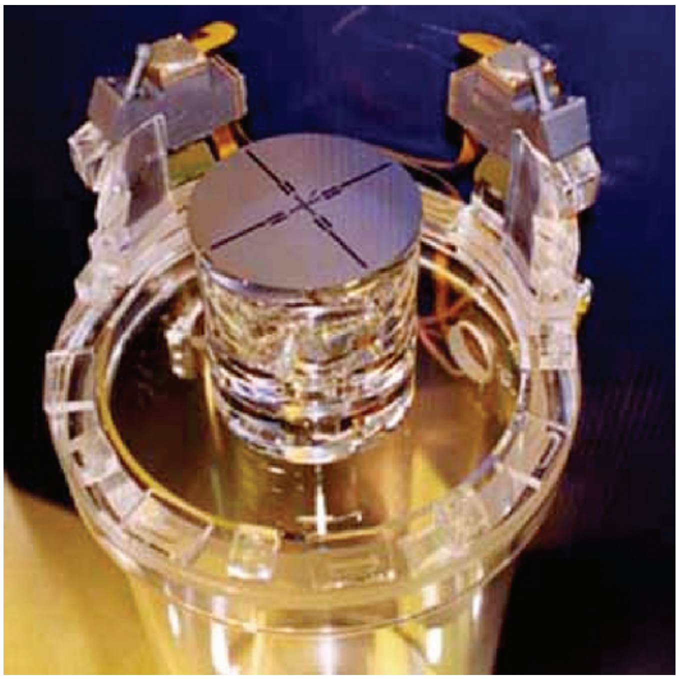


Photo Credit: GP-B Photo Archive, Stanford University

Lockheed Martin in Palo Alto, Calif., is a major subcontractor on the project and was responsible for designing and constructing the unique spacecraft, as well as some of its major payload components.

Conceptually, the GP-B experiment is quite simple. A telescope is rigidly connected to the gyroscope housings. In flight, the telescope always points to the same guide star. Initially, the gyroscopes' spin axes are aligned through the bore sight of the telescope to this guide star. A set of superconducting readout systems, called SQUIDs (Superconducting QUantum Interference Devices) detect minute changes in each gyroscope's spin axis orientation. Changes in the spin axis alignment of the gyroscopes are a direct measurement of the geodetic and/or frame-dragging effects of general relativity.

A GP-B Gyroscope

Photo Credit: Don Harley

GP-B's gyroscopes, each of which has now completed over a billion revolutions since launch, are near perfect, in that they limit any drift resulting from electrical and mechanical imperfections or forces acting on them. The GP-B instrument is designed to measure changes in gyroscope spin axis orientation to better than 0.5 milliarcseconds (1.4×10^{-7} degrees) over a one-year period. This minuscule angle is approximately the width of a human hair as viewed from 32 kilometers (20 miles) away.

According to the laws of Newtonian physics, a perfect gyroscope, which is experiencing no external forces, will not drift. In the GP-B experiment this would mean that once a gyroscope is spinning in alignment with the guide star, it would stay aligned with that star forever. In the early 1960s, based on Einstein's general theory of relativity, Dr. Leonard Schiff, chairman of the Physics Department at Stanford, predicted that the geodetic and frame-dragging effects would slightly change an orbiting gyroscope's spin axis alignment in relation to the guide star.

GP-B's Technology

The major components of the science instrument (four gyroscopes, the optical telescope, the mounting block) are all made of fused quartz. Quartz is very stable over wide temperature ranges—expanding and contracting very little and uniformly. Speedring, Inc., in Cullman, Ala., machined many of these precision parts, including the gyroscope housings.

The Cryogenic Probe

Photo Credit: Russ Underwood, Lockheed Martin Corporation

The science instrument's optical telescope has an aperture of 14.0 centimeters (5.5 inches). Throughout the experiment, it is pointed at the center of GP-B's guide star IM Pegasi (HR 8703), which provides the experiment's frame-of-reference in space.

Technicians at the Marshall Center originally built the highly advanced polishing equipment needed to manufacture the gyroscope rotors. Engineers at Stanford developed the thin-film technology for placing a superconductive metal coating of Niobium on the gyroscope rotors.

The gyroscope rotors are perhaps the most spherical objects ever made. If the gyroscope rotors were enlarged to the size of the Earth, the tallest mountain or the deepest ocean ravine would be only 2.4 meters (8.0 feet) in height. These gyroscopes are sufficient to achieve the specified 0.5 milliarcsecond (1.4×10^{-7} degrees) per year accuracy in their drift rate measurements.

The Dewar

Photo Credit: Russ Underwood, Lockheed Martin Corporation

The GP-B instrument assembly is contained within the 2.7 meter (9.0 foot) long, cigar-shaped cryogenic probe. Surrounding the probe is a shield of superconducting lead foil. This "lead bag" shields the instrument from interference from the Earth's magnetic field. In turn, the probe and lead bag are contained within a large thermos-like Dewar, containing 2,441 liters (645 gallons) of superfluid helium. The cryogenic temperature of 1.8 Kelvin is necessary to cause the niobium metal coating on the gyroscope rotors to become super-conducting. The direction of the rotor's spin axis is determined through the magnetic moment ("London moment") generated by a spinning super conductor.

The superfluid helium inside the Dewar serves both as a refrigerant for maintaining the probe's cryogenic environment and, when vented from the Dewar in the form of helium gas, as a propellant for controlling the spacecraft's position and roll rate.

A minuscule amount of heat is conducted into the Dewar via some 400+ cables and tubes that connect the various systems inside the probe with control and instrumentation systems mounted on the spacecraft frame and also by light radiating down through the telescope bore.

Fairing installation on the launch pad

Photo Credit: Russ Underwood, Lockheed Martin Corporation

This heat causes some of the liquid helium to boil off. A "porous plug," invented at Stanford, allows helium gas to escape from the Dewar, drawing heat out with it, while leaving behind the liquid helium and maintaining the necessary cryogenic temperature and pressure inside the Dewar. The escaping helium gas is cycled past cooling shields in the Dewar's outer layer, and then vented into space through eight pairs of micro-thrusters on the spacecraft frame. Based on data from the telescope and one of the four gyroscopes that serves as a proof mass (center of mass for the spacecraft), the helium gas escaping from the Dewar is carefully metered through these micro-thrusters so that the spacecraft flies around the proof mass gyroscope, maintaining a "drag free" orbit.

The Gravity Probe B Launch

Photo Credit: Bill Hartenstein—www.ktb.net/%7Ebillmeco

The GP-B Launch

The GP-B spacecraft launched from Vandenberg Air Force Base, Calif., atop a Boeing Delta II rocket at 9:57:24 AM PDT on April 20, 2004.

The solar arrays deployed right on schedule, 66 minutes after launch, and the Boeing Delta II launch vehicle second stage released the space vehicle in a nearly perfect circular polar orbit, at an altitude of ~642 kilometers (~400 miles). The orbit insertion was so precise that no orbit trim or correction was required.

Separation viewed live from a video camera on-board the 2nd stage booster

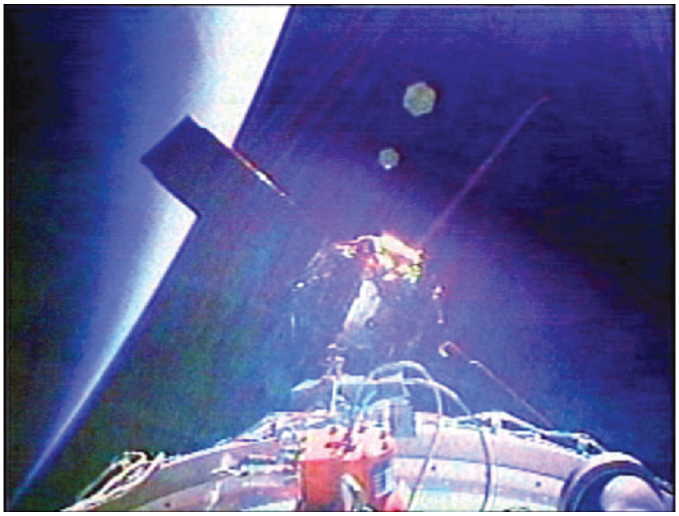


Photo Credit: NASA video camera on the 2nd stage booster

The IOC Phase

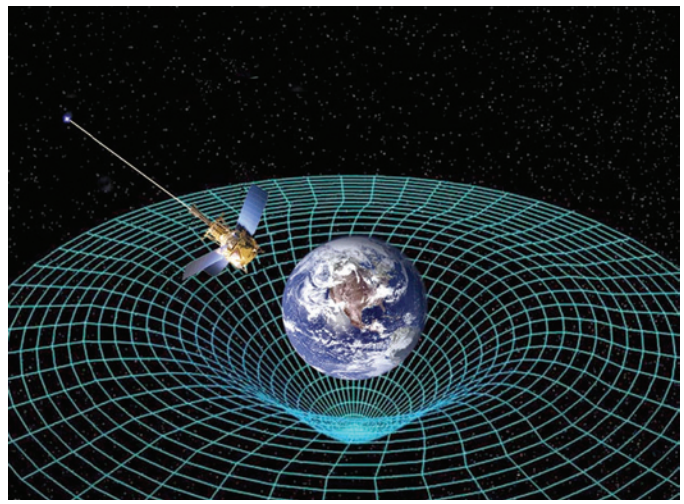
The Initialization and Orbit Checkout (IOC) phase of the mission lasted four months. During this period, all of the spacecraft's systems and instruments were systematically initialized, calibrated, and tested. A number of adjustments were made to the spacecraft's Attitude and Translation Control (ATC) system software in order to correct for two micro-thrusters that failed to function correctly due to particle contamination after launch. Since the ATC control software was modified and fine- tuned, the science telescope has consistently been able to quickly locate and lock onto the guide star, IM Pegasi, after the spacecraft emerged from behind the Earth, over the North Pole each orbit.

The Mission Operations Center at Stanford

Photo Credit: Bob Kahn, GP-B Public Affairs, Stanford Univ.

The spacecraft's roll rate along its main axis (also the axis of the telescope and the gyroscopes) was set at 0.7742 rpm (77.5 seconds per revolution), thereby averaging out any thermal effects and other tiny forces acting on the gyroscopes that are unrelated to the effects of general relativity. The four gyroscope suspension systems were tested, and the gyroscopes were gradually spun up, one by one, to science speeds averaging approximately 72 Hz (4,300 rpm).
After the gyroscopes were spun up, their spin axes were all aligned with the guide star. On August 28, 2004, with all necessary preparations completed, GP-B began its 10-month science (data collection) phase.

Drawing of GP-B in Earth's gravity well



Drawing: GP-B Image Archive, Stanford University

The Science Phase

As of the end of January 2005, GP-B has been collecting science data for five months and is now halfway through the science phase of the mission. The GP-B spacecraft autonomously collects real-time data from over 9,000 sensors. This data is stored in an on-board solid state recorder (SSR), which has the capacity to hold about 15 hours of both system status and science data. The spacecraft communicates with the Mission Operations Center (MOC) at Stanford University via a network of NASA telemetry satellites, called TDRSS (Tracking and Data Relay Satellite System), and with NASA ground tracking stations.

The GP-B spacecraft typically completes six to ten TDRSS "passes" (communication sessions) and four ground station passes daily. Commands and basic spacecraft health and status data are transmitted through TDRSS, which has a low data rate, but good global coverage. Science data, which requires a high data rate is transmitted through ground stations. Due to GP-B's polar orbit, GP-B communicates with ground stations in Poker Flats, Alaska, Svalbard, Norway, and Wallops, Va.

Einstein's Legacy

The science phase of the mission will be completed in June, 2005. Then, after a one-month instrument re-calibration period to ensure the accuracy and reliability of the data collected, analysis of the data will begin. Up to one year has been allocated for the data analysis, and we will then be in a position to compare GP-B's experimentally measured values of geodetic and frame-dragging effects with the theoretical values resulting from Einstein's 1916 general theory of relativity. Will the Time magazine "Man of the 20th Century" be right? Tune in next year….

Gravity Probe B Quick Facts

Measurements	
Predicted Drift-Geodetic Effect	6.61 arcseconds (1.84×10^{-3} degrees) per year
Predicted Drift - Frame-Dragging	0.041 arcseconds (1.14×10^{-5} degrees) per year
Required Accuracy	Better than 0.5 milliarcseconds (1.4×10^{-7} degrees) per year
Gyroscopes (4)	
Shape	Spherical (Sphericity < 40 atomic layers from perfect)
Diameter	3.8 centimeters (1.5 inches)
Composition	Homogeneous fused quartz
Coating	Niobium (uniform layer 1,270 nanometers thick)
Spin Rate	72 Hz (4,300 rpm) average
Drift Rate	Less than 10^{-11} degrees/hour
Telescope	
Composition	Homogeneous fused quartz
Length	35. 6 centimeters (14.0 inches)
Aperture	14.0 centimeters (5.5 inches)
Focal length	3.8 meters (12.5 feet)
Mirror diameter	14.2 centimeters (5.6 inches)
Guide Star	HR 8703 (IM Pegasi)
Proper motion location accuracy	0.00015 arcseconds (4.1667×10^{-8} degrees) per year

Dewar	
Size	2.7 meters (8.9 feet) tall, 2.6 meters (8.7 feet) diameter
Contents	2,441 liters (645 gallons) superfluid helium @ 1.8 Kelvin (-271.4°C)
Spacecraft	
Length	6.4 meters (21.1 feet)
Diameter	2.6 meters (8.7 feet)
Weight	3,100 kg (3.4 US tons)
Power	Total Power: 606 Watts (Spacecraft: 293 W, Payload: 313 W)
Batteries (2)	3 5 Amp Hour
Pointing Accuracy	0.2 arcseconds (5.6×10^{-5} degrees)
Drag-free capability	10^{-11} g
Launch Vehicle	
Manufacturer & Type	Boeing Delta II, Model 7920-10
Length	38.6 meters (126.6 feet)
Diameter	3.0 meters (9.8 feet)
Weight	231,821 kg (255.5 U.S tons)
Stages	2
Fuel	9 strap-on solid rocket motors; kerosene and liquid oxygen in first stage; hydrazine and nitrogen tetroxide in second stage
Orbit	
Characteristics	Polar orbit at 642 kilometers (400 miles), passing over one of the poles every 48.75 min.
Semi-major axis	7,027.4 km (4,366.6 miles)
Eccentricity	0.0014
Apogee altitude	659.1 km (409.5 miles)
Perigee altitude	639.5 km (397.4 miles)
Inclination	90.007°
Right Ascension of ascending. node	163.26°
Mission	
Launch	April 20, 2004, 9:57:24 am PDT
Site	Vandenberg Air Force Base, CA
Duration	11 months, following 120 days of initialization and checkout after launch

http://www.nasa.gov
http://einstein.stanford.edu
http://www.gravityprobeb.com

Explore. Discover. Understand.

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