

The Relativity Mission at Stanford University

- **Hardware-in-the-loop set up for general relativity experiment**
- **Simulation of gyroscopes that orbit the Earth 400 miles away**

While Albert Einstein's theory of General Relativity has been around for nearly a century, tests confirming its ideas are few and far from conclusive. Gravity Probe B is an experiment developed by NASA and Stanford University that will measure how space and time are influenced by the presence of Earth. dSPACE enables a hardware-in-the-loop set-up to test the highly sensitive electronic system of the most stringent and precise test of general relativity ever done.

American scientists calculated that according to Einstein's theory about space-time curvature, a rotating massive body should slowly drag space and time around with it – an effect called frame dragging. This force was supposed to push a gyroscope's axis out of alignment as it orbits the Earth. Gravity Probe B (GP-B) will use four gyroscopes to prove this prediction and measure the frame-dragging effect to a precision of 1% or better. It will also measure the geodetic effect, a result of the warping of space-time, with an accuracy of 0.01%.

The Physics of Gyroscopes

Gyroscopes are not only common traditional toys, today they are used as high-tech gyroscopes in gyrocompasses, like in advanced navigation systems on the Space Shuttle. There is one feature that makes them so interesting for that purpose: Fast rotating gyroscopes tend to keep a stable spin axis. If a force acts perpendicular to the rotation axis, the gyroscope's angular momentum (generated by its own perpendicular movement) presents a strong counterforce.

Axis Movement by a Hair's Width

GP-B will place the incredibly precise gyroscopes in polar Earth orbit at 400 miles. Each gyroscope spin axis will be aligned with the inertial axis of the rotating satellite. The satellite and its four gyroscopes will point toward a distant star, which will be used as the inertial reference. During the year, General Relativity predicts that the gyroscopes will turn in two directions. The geodetic effect will tend to push the gyro axes in a direction perpendicular to the

frame-dragging effect, which allow it to be measured separately. GP-B will keep the telescope continuously pointed at the original guide star. After a year, Einstein's General Theory predicts that the axis of the gyroscope will have moved six arcseconds due to the curvature of space-time and 42 milliarc-seconds (the width of a human hair, seen from a quarter mile away) due to the frame-dragging effect.

The Gyroscope Suspension System

The gyroscope quartz rotors are the roundest objects ever machined. They are each about the size of a ping-pong ball and will spin at about 10,000 rpm. We have a Gyroscope Suspension System (GSS) that electrostatically suspends the spherical gyroscope.



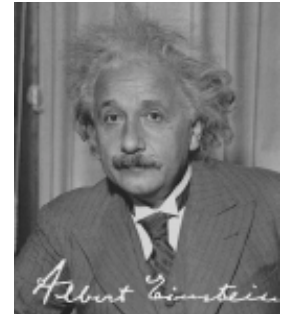
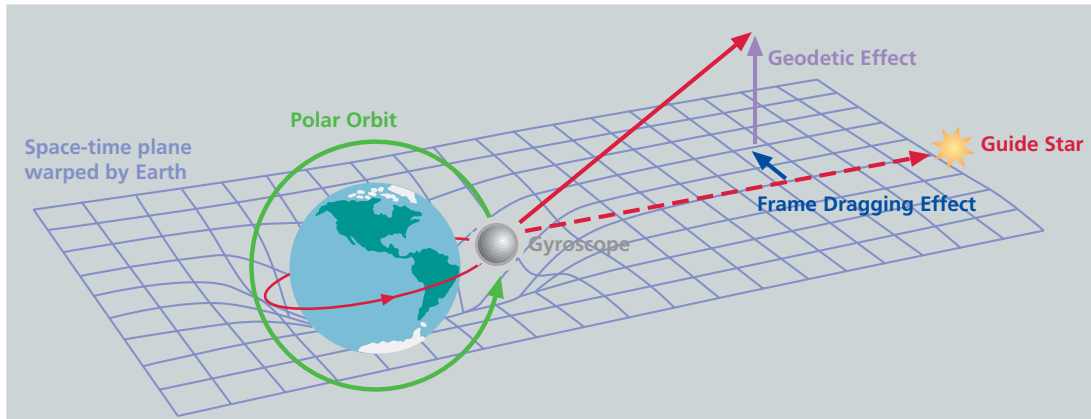
The gap between the rotor and the six suspension electrodes is less than 20 micrometers.

The GSS suspends the rotor by measuring the capacitance between the rotor surface and 3 pairs of electrodes, and if the rotor is centered,

the rotor/electrode capacitance of a pair will be equal. If not, the GSS capacitance bridge will output an error voltage. This voltage (and the voltage of the other 2 bridges) will be used to determine the necessary correction voltages needed to force



The behavior and properties of common traditional gyroscopes are used in the GP-B experiment.



Scientists often compare the fabric of space to a rubber sheet, with the Earth denting the surface, thus curving the paths of passing objects, known as geodetic effect. This is caused by the Earth's physical presence. The rotation of our planet twists the sheet and distorts time a little, an

effect called frame dragging. So Earth's own gravity and rotation should drag space and time just a little and thus pull the gyroscope spin axes slightly out of position. As both effects are so small they require incredibly precise instruments for the Gravity Probe B experiment.

the rotor toward the capacitive center, and an appropriate voltage will be applied by the GSS to each of the electrodes.

The Gyroscope Simulator

The GSS must undergo serious testing before it can suspend flight gyroscopes. Therefore, we needed a gyroscope simulator for GSS inputs and outputs and that's where dSPACE comes in.

We have a mechanical representation of a gyroscope consisting of 6 parallel plate capacitors. Their capacitances are controlled using a Simulink model compiled and downloaded to the DS1005 PPC Board. The separation of the parallel plates is measured using a capacitance bridge. This measurement is read into a Simulink model via the DS4002 Timing and Digital I/O Board. The gyroscope model determines the next position and sends it to the controller Simulink block, where it converts the request into a voltage command communicated again via the DS4002 to a piezo actuator, which moves one plate on each of the parallel plates such that the appropriate set of capacitances is presented to the GSS bridge. While this is going on, the GSS is commanding voltages to control the position of what it thinks is a gyroscope. These 6 voltages are read into the Simulink model using the DS2003 Multi-Channel A/D Board. They enter the gyro model and are converted to forces providing the dynamics introduced

by the suspension system.

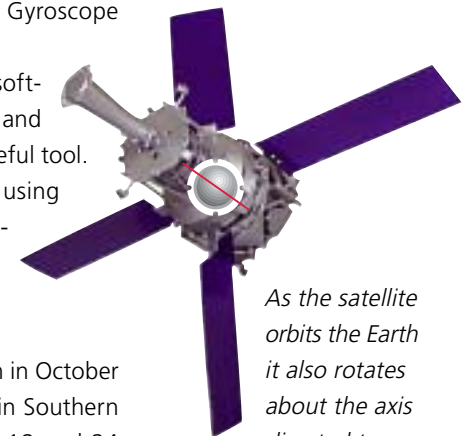
In the end we can present the dynamic equivalent of a gyroscope orbiting 400 miles above the surface of the Earth to the Gravity Probe B Gyroscope Suspension System.

We also use ControlDesk experiment software to monitor variables, acquire data and adjust parameters. It has been a very useful tool. With the easy learning curve involved using the Simulink interface, we had our simulation up and running in two days.

GP-B is to be Launched this Year

The GP-B satellite is scheduled to launch in October 2002 from Vandenberg Air Force Base in Southern California with a mission life between 18 and 24 months. By then, not only will GP-B have faced the challenges of inventing basic new technologies to create this experiment, but it will also have combined the efforts of scientists from numerous fields. GP-B is the most thoroughly researched program ever undertaken by NASA. For further details please see "The story of GP-B" at <http://einstein.stanford.edu>.

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As the satellite orbits the Earth it also rotates about the axis directed toward the guide star, the inertial reference. The GSS suspension system controls the rotor position to within 1 nanometer of this rotational axis.