Editorial
>> Marc Cheves, LS

Angular Accuracy

Whether you first learned it in an early science class, or recall it twirling across the opening episodes of *The Twilight Zone*, Einstein's $E=mc^2$ formula expressed a *special* theory of relativity. Based on that theory, the development of nuclear energy was made possible, and with it, the atomic bomb. But it is Einstein's *general* theory of relativity that has been more difficult to understand and prove.

In 2004, I wrote a web-exclusive article about a space experiment that was attempting to verify Einstein's general theory. While I don't pretend to understand Einstein's theory, I was intrigued by the groundbreaking science needed to mount the experiment, and there were several aspects I felt surveyors would enjoy, such as the needed angular accuracy, etc. Additionally, four GPS receivers were onboard the satellite to provide centimeter-level positioning information.

The results of the experiment were released on May 4, 2011, and can be found at: http://einstein.stanford.edu/highlights/status1.html. A 218Kb PDF of the 2004 article, complete with lots of images and more explanatory text, can be found in the web-exclusive area of our website. Here's an excerpt:

Long before GPS and the reliance on geoids to establish orthometric heights, surveyors' plumb lines were affected by local gravity variations, such as nearby mountains. Today, about the best angular accuracy we can achieve is on the order of tenths of a second. Stanford University's Gravity Probe B, with its capability of resolving angles to the tenth of a millarcsecond, will explore the fine structure of the Earth's gravitational field.

Proposed more than 40 years ago, and based on work stretching back to the 1800s and Einstein's 87-year-old special theory, the Gravity Probe B (GP-B) experiment brought together an incredible array of new technology. In the late 1950s, two scientists came up with the idea of launching an extremely stable gyroscope into an orbit that would cross the earth's poles. If Earth was twisting space-time, the gyroscope's axis of rotation would tilt. By keeping the gyroscopes precisely pointed at a distant star, any variation in the axes of the gyroscopes would be detected. In polar orbit, with the axes of the gyros pointing at the star, the geodetic and frame-dragging effects would show up at right angles to the axes. (Note: these terms are defined in the PDF.)

Several technologies had to be developed to make the experiment possible, including the creation of the gyroscopes themselves. After much experimentation, scientists decided to use fused silica and single crystal silicon as the moving part, or rotor. The spheres were ground and polished to within 0.01 microns of perfect sphericity. If enlarged to the size of the earth, the highest mountains and deepest valleys would be within eight feet of sea level.

Assembling the telescope also presented several challenges. Fourteen inches long, with a 5.6 inch aperture (focal length 12.5 feet), it was able to pinpoint the center of IM Pegasus to within 0.1 millarcseconds. To put the tiny tolerances and design objectives into perspective, consider the following: the detection capability of the assembly was less than 0.002% of a degree, which corresponds to a gyro tilt of 0.1 millarcsecond. From a human perspective, the distance subtended by this angle would be like looking at the edge of a piece of paper 100 miles away. Similarly, this subtended angle would result in a distance of five feet if it were extended to the moon.

Due to its cost of $700 million, the GP-B experiment was not without controversy, but by succeeding, a spin-off benefit for surveyors might be a dramatic refinement of our wildly undulating geoid. GP-B, with its capability of resolving angles to the tenths of millarcseconds, makes our angular work today look coarse, to say the least. As we learn to deal more and more with the geoid, any refinements in it will be welcome.

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