Cryogenic test probes Einstein's equivalence principle, general relativity, and spacetime 'foam'

January 5 2017, by Lisa Zyga

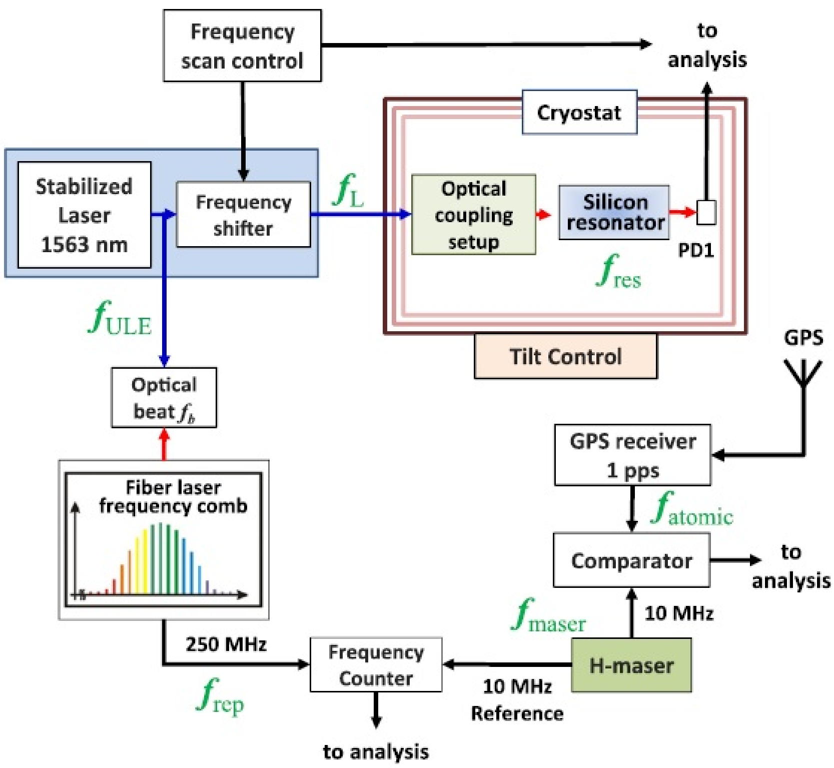

Illustration of the experimental set-up, in which scientists attempted to detect any change in the length of a cryogenic silicon resonator. They detected no change, in support of the equivalence principle. Credit: Wiens et al. ©2016 American Physical Society

(Phys.org)—Physicists have performed a test designed to investigate the effects of the expansion of the universe—hoping to answer questions such as "does the expansion of the universe affect laboratory experiments?", "might this expansion change the lengths of solid objects and the time measured by atomic clocks differently, in violation of Einstein's equivalence principle?", and "does spacetime have a foam-like structure that slightly changes the speed of photons over time?", an idea that could shed light on the connection between general relativity and quantum gravity.

In their study published in *Physical Review Letters*, E. Wiens, A.Yu. Nevsky, and S. Schiller at Heinrich Heine Universität Düsseldorf in Germany have used a cryogenic resonator to make some of the most precise measurements yet on the length stability of a solid object. Overall, the results provide further confirmation of Einstein's equivalence principle, which is the foundation on which the theory of general relativity is based on. And in agreement with previous experiments, the researchers found no evidence of spacetime foam.

"It is not easy to imagine ways of testing for consequences of the expansion of the universe that occur in the laboratory (as opposed to studying distant galaxies)," Schiller told *Phys.org*. "Our approach is one way to perform such a test. That we have not observed any effect is consistent with the prediction of general relativity."

Over the course of five months, the researchers made daily measurements of the resonator's length by measuring the frequency of an electromagnetic wave trapped within it. In order to suppress all thermal motion, the researchers operated the resonator at cryogenic temperature (1.5 degrees above absolute zero). In addition, external disturbances, such as tilt, irradiation by laser light, and some other effects that might destabilize the device were kept as small as possible.

To measure the resonator's frequency, the researchers used an atomic clock. Any change in frequency would indicate that the change in length of the resonator differs from the change in time measured by the atomic clock.

The experiment detected virtually no change in frequency, or "zero drift"—more precisely, the mean fractional drift was measured to be about 10^{-20}/second, corresponding to a decrease in length that the researchers describe as equivalent to depositing no more than one layer of molecules onto the mirrors of the resonator over a period of 3000 years. This drift is the smallest value measured so far for any resonator.

One of the most important implications of the null result is that it provides further support for the equivalence principle. Formulated by Einstein in the early 1900s, the equivalence principle is the idea that gravity and acceleration—such as the acceleration a person would feel in an upward-accelerating elevator in space—are equivalent.

This principle leads to several related concepts, one of which is local position invariance, which states that the non-gravitational laws of physics (for example, electromagnetism) are the same everywhere. In the current experiment, any amount of resonance drift would have violated local position invariance. Along similar lines, any amount of resonance drift would also have violated general relativity, since general relativity prohibits changes to the length of solid objects caused by the expansion of the universe.

Finally, the experiment also attempted to detect the hypothetical existence of spacetime foam. One of the effects of spacetime foam would be that repeated measurements of a length would produce fluctuating results. The constant measurement results reported here therefore indicate that such fluctuations, if they exist at all, must be very small.

In the future, the researchers hope that the extremely precise measurement technique using the cryogenic resonator could be used for other applications.

"One of the greatest outcomes of this work is that we have developed an approach to make and operate an optical resonator that has extremely little drift," Schiller said. "This could have applications to the field of atomic clocks and precision measurements—for example, for the radar tracking of spacecraft in deep space."

More information: E. Wiens, A. Yu. Nevsky, and S. Schiller. "Resonator with Ultrahigh Length Stability as a Probe for Equivalence-Principle-Violating Physics." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.117.271102. Also at arXiv:1612.01467 [gr-qc]