Accelerators can search for signs of Planck-scale gravity

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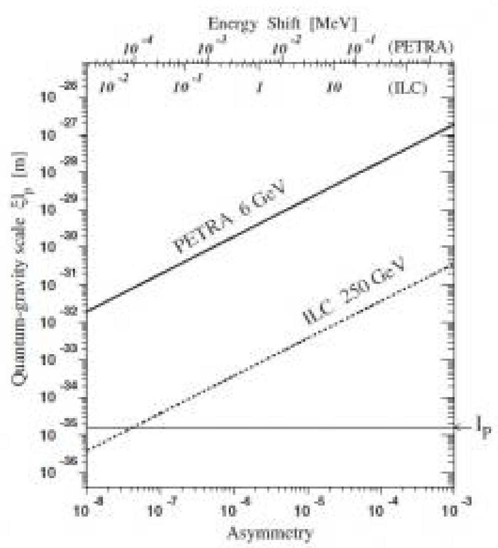

The PETRA-III accelerator at DESY and the proposed International Linear Collider (ILC) could test the energy-dependent bending of light by gravity at very small scales. Tests could measure two effects: refractivity, which produces energy shifts (upper scale) and birefringence, which produces a Compton edge asymmetry (lower scale). The Planck length is shown by an arrow. Image credit: Vahagn Gharibyan.

(Phys.org)—Although quantum theory can explain three of the four forces in nature, scientists currently rely on general relativity to explain the fourth force, gravity. However, no one is quite sure of how gravity works at very short distances, in particular the shortest distance of all:

the Planck length, or 10^{-35} m. So far, the smallest distance accessible in experiments is about 10^{-19} m at the LHC.

Now in a new paper published in Physical Review Letters, physicist Vahagn Gharibyan of Deutsches Elektronen-Synchrotron (DESY) in Hamburg, Germany, has proposed a test of quantum gravity that can reach a sensitivity of 10^{-31} m down to the Planck length, depending on the energy of the particle accelerator.

As Gharibyan explains, several models of quantum gravity predict that empty space near the Planck length may behave like a crystal in the sense that the space is refractive (light is bent due to "gravitons," the hypothetical particles that mediate gravity) and has birefringence/chirality (the light's bending degree also depends on the light's polarization).

In quantum gravity, both refractivity and birefringence are energy-dependent: the higher the photon energy, the stronger the photon-graviton interaction and the more bending. This correlation is the opposite of what happens when photons interact with electromagnetic fields or matter, where these effects are suppressed by photon energy. The predicted correlation also differs from what happens according to Newtonian gravity and Einstein's general relativity, where any bending of light is independent of the light's energy.

"If one describes gravity at the quantum level, the bending of light by gravitation becomes energy-dependent – unlike in Newtonian gravity or Einstein's general relativity," Gharibyan told *Phys.org*. "The higher the energy of the photons, the larger the bending, or the stronger the photon-graviton interaction should be."

Gharibyan suggests that this bending of light according to quantum gravity models may be studied using high-energy accelerator beams that probe the vacuum symmetry of empty space at small scales. Accelerators could use high-energy Compton scattering, in which a photon that scatters off another moving particle acquires energy, causing a change in its momentum. The proposed experiments could detect how the effects of quantum gravity change the photon's energy-momentum relation compared with what would be expected on a normal scale.

For these experiments, the beam energy is vital in determining the sensitivity to small-scale effects. Gharibyan estimates that a 6 GeV energy lepton accelerator, such as PETRA-III at DESY, could test space birefringence down to 10^{-31} m. Future accelerators that could achieve energies of up to 250 GeV, such as the proposed International Linear Collider (ILC), could test birefringence all the way down to the Planck length. For probing refractivity, Gharibyan estimates that a 6 GeV machine would have a sensitivity down to 10^{-27} m, while a 250 GeV machine could reach about 10^{-31} m.

As Gharibyan explains, probing Planck-scale gravity in this way is somewhat similar to investigating nanoscale crystal structures.

"Conventional crystals have cell sizes around tens of nanometers and are transparent to, or do not interact with, photons with much larger (m or mm) wavelengths," Gharibyan said. "In order to investigate crystal cells/structures, one needs photons with compatible nm wavelength: X-rays. However, visible light with wavelengths 1000 times more than the crystal cell can still feel the averaged influence of the cells: the light could be reflected singly or doubly. Comparing this to the Planck-length crystal, we don't have photons with a Planck wavelength or that huge energy. Instead, we are able to feel the averaged effects of Planck crystal cells – or space grains – by using much [relatively] lower-energy photons."

In fact, as Gharibyan has found, there are already experimental hints of gravitons.

"This work presents evidence for quantum gravity interactions by applying the developed method to gamma rays faster than light, which I found earlier in data from the largest US and German electron accelerators," he said. "The absence of any starlight deflection in the cosmic vacuum hints that Earth's gravitons should be considered responsible for the observed bending of the accelerators' gamma rays."

Gharibyan found that data from the now-closed 26.5 GeV Hadron-Electron Ring Accelerator (HERA) at DESY measured a Planck cell size of 2.6×10^{-28} m, and data from the mothballed 45.6 GeV Stanford Linear Collider (SLC) at Stanford University in the US measured a space grain size of 3.5×10^{-30} m. While these results provide some hints of Planck-scale gravity, neither of these experiments was designed as a tool to specifically test gravity, so Gharibyan warns that uncontrolled pieces of setups could mimic observed effects.

If Gharibyan's newly proposed experiments are performed, they would provide the first direct measurements of space near or even at the Planck scale, and by doing so, offer a closer glimpse of gravity in this enigmatic regime.

More information: Vahagn Gharibyan. "Testing Planck-Scale Gravity with Accelerators." *Physical Review Letters* 109, 141103 (2012). DOI: 10.1103/PhysRevLett.109.141103

Vahagn Gharibyan. "Possible observation of photon speed energy dependence." *Physics Letters B* 611 231-238 (2005). DOI: 10.1016/j.physletb.2005.02.053