Generally Speaking: A Primer on General Relativity

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"The one sentence statement of general relativity is that 'gravity is the curvature of spacetime,'" explains Dr. Sean Carroll, assistant professor of physics at the University of Chicago. "Really, the differences come in understanding what that sentence means."

Carroll says that origin of the theory of general relativity dates to 1905, when scientists, notably including Albert Einstein, realized that space and time are related characteristics of a four-dimensional existence. "When you meet someone for coffee," says Carroll, "you have to give four numbers of where to meet. Three of them are in space — latitude, longitude, and height above ground — and the fourth is what time to meet."

However, within this new 4-D framework, says Carroll, Einstein could not understand gravity, and how it worked in spacetime. He decided that rather than being a force, like electromagnetism, gravity must be a property: a geometric curvature. Even though we agree that the angles of a triangle add up to 180 degrees, this rule changes when a curve is involved. When that same triangle is put on a sphere, the angles add up to more than 180 degrees. Likewise, when the curvature of spacetime is recognized, the basic rules thought to apply to gravity are changed.

Lately, though, general relativity has been looked at closely. Carroll says that while no evidence exists for the overthrow of the theory of general relativity, there are some points where general relativity may not apply. "General relativity is doing really well," he explains to *PhysOrg.com*, "but there are two places where it might break down."

These two places, Carroll says, have to do with very short distances and on very large scales. With very short distances, in terms of quantum mechanics, there are problems with gravity and with general relativity. The theory does not apply in the same way as it does with longer spacetime distances. "In classical general relativity, spacetime has a geometry; in quantum gravity, there should be a wave function that tells us what the likelihood is that spacetime has one of various geometries," Carroll explains. Even though no experiment exists yet that has cracked the theory of quantum gravity, a new test is being developed in Europe to try and work toward just that (read about it on *PhysOrg.com*: http://www.physorg.com/news12054.html).

The other breakdown might occur on large scales. There is still much about the larger scales that remain hypothetical. General relativity is one of those things. "There is still a question of how much curvature is caused by a certain amount of energy and mass," says Carroll. "Einstein suggested an equation that related energy to the curvature of spacetime, but it may be right in some circumstances and not in others." He explains that breaking down dark energy and matter is necessary to understand the implications, but that, so far, their existence is only known through their gravity. "That could be a sign that general relativity breaks down at this scale."

Carroll also addresses the case of special relativity. "Special relativity is special because it is a special case of general relativity. General relativity is, well, general, and special relativity is one particular case."

In the case of special relativity, gravity is "turned off." Carroll explains that gravity can be ignored in this subset because it is such a weak force. "Special relativity deals with the idea that different people moving at different velocities will have different perceptions of what they see, and gravity is not taken into account.” But, he continues, work with particle accelerators show that special relativity is extremely accurate for many experiments.

Understanding general relativity is more a function of realizing that gravity is a property of spacetime, and one of its properties is gravity, which is actually a curvature. The effects we see, explains Carroll, comes from the fact that particles cannot move in a straight line. “Particles are trying to move in straight lines,” he says, “but there are no straight lines because spacetime is curved.”

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