ASK THE PROFESSOR

Especially One Who Knows the Answer

Hypothesis Non Fingo: But, How Can There Be Action At a Distance?

Isaac Newton's stunning success, the theory of gravity, seemed disturbing to many contemporaries; it required one to accept that heavenly bodies could act on one another at a distance with nothing intervening. To some, Newton's "gravity" was a step backwards to a time when conceptual inventions like "instincts" and "humours" were invoked as explanations of scientific phenomena—*explanations* that explained nothing. Newton replied, "I feign no hypotheses," *hypotheses non fingo.* But many of us never got beyond this stumper in physics and we would like know how action at a distance is possible. So we asked an Oakland expert.

Prof. David Garfinkle of the Oakland University Physics Department is a widely cited expert on gravitation. He studies gravitational collapse, with emphasis on the singularities of black holes and the Big Bang. He has recent papers in Physical Review D on collapse of gravitational waves and on critical behavior at the threshold of black hole formation. And, in person, he seems to know a lot about gravity. When we posed our question to him, he offered this reply:

To answer this question, it is helpful to start with an analogous situation that we are more familiar with: radio. We know that the radio programs we listen to on our radio receivers are produced at radio stations that are some distance away from us. So how does the radio station "act at a distance on our radio receivers with nothing intervening"? The answer is that the radio station does not really act at a distance but rather produces changes in its local area and these changes propagate until they reach our radio receiver. To be more explicit, at the radio station, electric currents are driven up and down in the station's antenna. These currents produce electric and magnetic fields in the immediate vicinity of the antenna and since the currents are changing rapidly, so are the fields produced. It turns out that changing magnetic fields produce electric fields, and changing electric fields produce magnetic fields. So the antenna produces changing fields in its immediate vicinity, these changing fields produce changing fields in their immediate vicinity and so on. The result is that the change in the fields propagates in all directions away from the antenna until finally those changing fields reach the antenna of our radio receiver. The changing electric field then produces a changing current in the receiver's antenna and this current is the signal that the receiver eventually uses (after tuning, amplification, etc.) to give us the sound of the radio program. All this propagation of changing electric and magnetic fields takes time, but not much. It happens at the speed of light (in fact light is also an electromagnetic wave differing from radio waves only in its much shorter wavelength). The speed of light is 186,000 miles per second (which comes out to more than 7 times around the world in one second) so we don't notice the short time that it takes to get the signal from the radio station to us.

Now what does this have to do with gravity? After all, Newton's theory of gravity doesn't talk about disturbances propagating at some speed. It simply says that the gravitational force that object A exerts on object B depends in a particular way on the masses of the objects and the distance between them. This particular aspect of Newton's theory was very disturbing to Einstein in the years between 1905 and 1915. In 1905 Einstein had developed his special theory of relativity and one consequence of special relativity is that it is impossible to send a signal faster than the speed of light. However if Newton's theory of gravity were correct then it would be possible to send an instantaneous signal: simply consider our two objects A and B, and move object A back and forth. According to Newton's theory, this should immediately cause a change in the force on object B and thus be a signal sent from A to B faster than light. Faced with this contradiction, Einstein might have been tempted to give up special relativity. Instead he decided that Newton's theory of gravity had to be wrong and that it needed to be replaced with a better theory.

It took Einstein until 1915 to find the correct theory, the general theory of relativity. One reason why it took so long is that the mathematics of general relativity is fairly complicated and abstract, describing gravity in terms of the geometry of space and time. However, for our purposes the description of how gravity gets from one point to another is essentially the same as our earlier description of radio waves (in fact for all but the extremely strong gravitational fields the complicated equations of general relativity simplify and become very similar to Maxwell's equations which describe the electromagnetic field). Masses change the spacetime geometry in their immediate vicinity in much the same way that electric charges make electric fields. This change in turn causes a change in the geometry in its immediate vicinity and so on until the gravitational effect is felt by a distant object.

Just as for radio waves, changes in the gravitational field propagate at the speed of light. This is the reason why Newtonian gravity works as well as it does. Since the speed of light is so fast, it is often difficult to distinguish between something that travels at the speed of light and something that is instantaneous.

In summary, the answer to the question is that in the correct theory of gravity (Einstein's general theory of relativity) there is no action at a distance. Rather, just as for radio waves effects are produced at a distance by the local propagation of change.