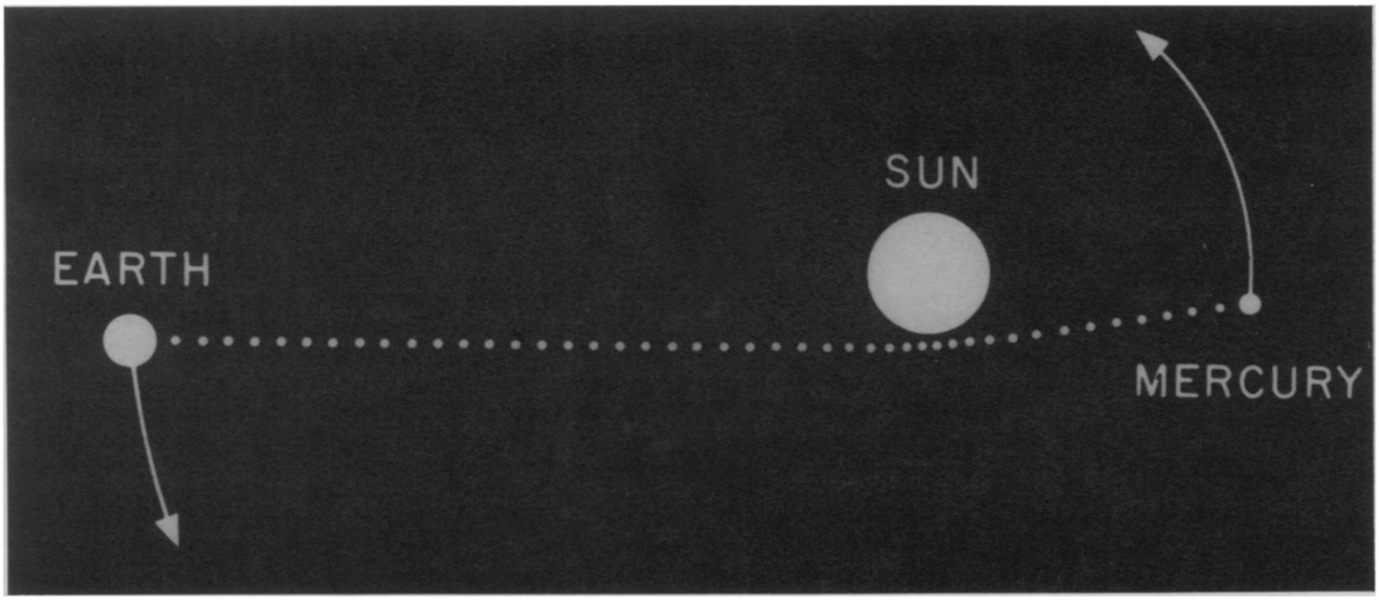

Lincoln Laboratory, MIT

Geometry of the radar test. Dots are bunched near the sun to show slowing. Some beam curvature is also shown.

general relativity survives a test

An experimental check, unforeseen by Einstein, fails to shake the theory. Better tests to come.

Was Einstein right? After more than 50 years of discussion and observation since his theory of general relativity was published, the answer still has to be: maybe.

Einstein had set himself the task of devising a theory in which the laws of mechanics would have the same mathematical form no matter from what frame of reference the actions of material bodies might be observed. This, since it explicitly included systems or reference frames that might be accelerated with respect to one another, went a step beyond the previously formulated theory of special relativity. Special relativity gives the laws of mechanics the same form only in reference frames that are moving at steady speeds with respect to one another.

To set up his general relativity theory, Einstein found that he had to make gravity disappear as a force. He chose therefore a formulation of space that turned gravity into a geometric effect. Space in the neighborhood of massive bodies became curved. It was this curvature that constrained the motion of other bodies, and gravity became the measure of this curvature.

The theory thus developed gave space a physical meaning that it had not had in the older Newtonian theory, where space had been regarded as pure emptiness. At this point the distinction between matter and space—that is, between something and nothing—begins to break down. Matter tends to appear as a graininess or lumpiness in the space, rather like raisins in Jello, as Dr. S. A. Goudsmit of Brookhaven National Laboratory once described it.

Special relativity, because it predicts that bodies will increase their mass as they increase their speed, has gathered an abundance of supporting evidence from thousands of elementary-particle experiments. The experimental case for general relativity is by no means as good.

Einstein admitted that the general theory as a whole was not susceptible to observational confirmation, but certain of its predicted consequences ought to be visible, and he suggested three tests that might be made. If they were successful, he felt they would lend credence to the theory. Last week the results of a fourth test, independently suggested, were announced.

Einstein's three tests included the bending of light rays in a gravitational field, which has been recorded during many solar eclipses since it was first done in 1919; excessive motion of the perihelion of the planet Mercury, confirmed by meticulous observations; and a change in the wavelength of light or similar radiation induced by a gravitational field. The last effect was most accurately demonstrated only a few years ago in experiments involving X-rays in earth's gravitational field.

The newest test was suggested in 1964 by Dr. Irwin I. Shapiro of Massachusetts Institute of Technology. It involves using interplanetary radar beams to test yet another Einsteinian prediction—namely that any electromagnetic radiation will slow down when it passes through an intense gravitational field.

The technique is to bounce a radar beam off another planet when the other planet is almost on the opposite side of the sun. The gravitational field of the sun should be strong enough to cause a perceptible slowing of the beam.

In fact, the slowing was calculated to be only about 200 microseconds in a total transmission time of about 22 minutes. Yet with equipment at MIT's Lincoln Laboratory—the 120-foot Haystack radio-radar telescope—the measurement could be made, and in 1967 it was accomplished by Dr. Shapiro and his colleagues: Drs. Gordon H. Pettengill, Michael E. Ash, Melvin L. Stone, William B. Smith, Richard P. Ingalls and Richard A. Brockelman. They used Mercury as the reflector. The result came out within 20 percent of the prediction, which is, coincidentally, the same accuracy as is usually claimed for the other tests of the theory.

All this evidence goes far to bolster Einstein's contentions, but it has not quieted the critics. They point out that 20 percent accuracy is not very exclusive; any other theory that could predict the same effects and gave amounts within 20 percent of Einstein's figures could fit the evidence. Furthermore, if a theory predicted part of any of these effects and its proponents at the same time brought forth some other plausible mechanism to account for the remainder, it too might stand on the available evidence.

But why throw stones at a good theory? Philosophical unease is one reason. Certain people have not been entirely happy with some of Einstein's basic assumptions, especially his interpretation of the statement that the strength of gravitation anywhere in the universe depends on all the matter in the universe (known as Mach's principle).

The mathematical intractability of the theory is another reason. Einstein's basic gravitational equation is virtually insoluble and many people have wished they could finagle the theory somehow to ease the mathematical difficulties.

A recent example of attempted modification is the theory put forward by Drs. Carl H. Brans and Robert H. Dicke (SN: 2/11/67, p. 144). Arguments from Mach's principle led them to question Einstein's way of representing gravitation mathematically. So they changed it. The result is a theory that, among other things, predicts only 92 percent of what Einstein predicted for the excess motion of Mercury's perihelion. (The total amount is only 1/21,600 of a full circle in a hundred years.)

How to explain the other eight percent? Dr. Dicke suggested that if the sun were oblate—slightly flattened at the poles—its gravitational field would be altered in such a way as to cause the extra motion of Mercury in a straightforward, pre-Einstein fashion. The theory of solar oblateness has run into serious objections, but if it should turn out to be true, then the Brans-Dicke gravitational theory could be said to fit the evidence as well as Einstein's.

Will the evidence ever allow a choice between Einstein and his critics? The radar experimenters hope to sharpen the accuracy of their measurement to within five percent. At this level it may be possible to begin making distinctions among rival theories. However, some of the theories include scale factors (sometimes called finagle constants by people who object to them) that allow a degree of stretching or squeezing to fit the evidence, thus increasing the difficulty of a decision. But for the present radar supports Einstein.

BIOSATELLITE 2

Radiation and weightlessness

A few days before Christmas in 1966, a crew of flies, wasps, beetles, bacteria, amoebas, spiderwort seedlings and other living things were carried into space aboard the first U.S. Biosatellite. On the ground, scientists sweated out the three days before the satellite's scheduled reentry, awaiting the mid-air snatch that would put capsule and crew back in their hands for study. At the last minute, the researchers were deprived of their triumph when a short-circuit kept a retrorocket from firing, thereby leaving the satellite stranded in orbit for days until gravity finally dumped it somewhere near Australia.

Last September a duplicate flight got back successfully (SN: 9/23/67 p. 299), and now, six months later, the delighted scientists are still poring over their data, many of which are in the form of direct descendants of the life forms on the flight.

The main thing offered by the flight, unobtainable on earth, was an extended period of weightlessness. To many of the investigators, however, even more important was the chance to subject their specimens to a combination of weightlessness and a controlled dose of radiation, provided by a measured, onboard source. They expected that radiation without gravity might have an effect different from the same radiation on earth.

In many cases they were right. But despite all sorts of laboratory tests, computer analyses and sleepless nights, they still do not know why.

The two factors are simply too different. What is the connection between gravity, a pure force, and radiation, the impingement of either solid particles or energy?

No one knows, but there are theories. One is that of Dr. Rudolf H. T. Mattoni of the NUS Corp. in Hawthorne, Calif., whose contributions to the satellite were two batches of bacteria, Salmonella and Escherichia coli. Identical batches, treated with matching doses of radiation, were kept in normal gravity on the ground. Both kinds of irradiated bacteria grew both faster and larger in space than on the ground; there were 48 percent more Salmonella in the spacecraft than in the ground control chambers, and 19 percent more E. coli.

"The reason for the greater growth in space," says Dr. Mattoni, "appears to be that without gravity to hold them down, the bacteria are randomly distributed throughout the growth medium, and access to food requires less energy, as does elimination of waste products."

In the case of more sophisticated organisms, the mechanisms linking zero-gravity and radiation seem more complicated. Dr. R. C. Von Borstel of Oak Ridge National Laboratory in Tennessee and Dr. Daniel S. Grosch of North Carolina State University found that developing wasp eggs apparently can recover from radiation damage in weightlessness, and that they also show a lower level of genetic damage than eggs irradiated on the ground.

Again, gravity's influence is still a mystery. It is possible, the researchers think, that weightlessness allows a slowing-down of the rapid cell-division and metabolic processes which eventually produce eggs in the wasps' ovarian tubes. This slows production of mature eggs, perhaps giving more time for repair processes to eliminate some of the damage caused by the radiation. Since the flight, the scientists have also found that the weightlessness has seemed to reduce the proportion of deaths due to radiation-caused genetic damage among embryos resulting from the eggs, again because slowdown gave time for repair.

Weightlessness, however, is not the only characteristic of space flight that may affect the effects of radiation. Another, first pointed out years ago by researchers in the Soviet Union, is vibration.

The Soviet space biology program is older than that of the U.S.—the second satellite ever launched, Russia's Sputnik 2, carried a dog—and has sent more living things into space. U.S. scientists, however, make the same complaint about the Russian biospace program as they do about the rest of the Soviet space effort: it's big, they feel, but pretty unsophisticated.