

BRK-008 · Testing gravity: 1915 to 1975

BRK · Conceptual Breaks

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A theory can accommodate an observation without being the only theory capable of accommodating it. This distinction became central to gravitational physics during the decades after general relativity appeared. The important change was not simply the accumulation of impressive confirmations. It was the construction of experiments, and of a common mathematical language, that could discriminate between explanations which agreed on much of the familiar evidence.

Between 1915 and 1975, gravity acquired a more demanding experimental question: which feature of a gravitational theory does this measurement actually constrain? A planetary orbit, a spectral frequency and a radar travel time do not test precisely the same claim. Their differences are useful. They prevent agreement in one setting from being mistaken for unrestricted confirmation everywhere.

1. An old discrepancy and a new prediction

Mercury's perihelion, the direction of its closest approach to the Sun, advances. Most of that motion was already explicable through Newtonian planetary perturbations. The remaining discrepancy, about 43 arcseconds per century, became a successful application of Einstein's 1915 theory. This was an explanation of an existing problem, rather than a prediction of a phenomenon nobody had noticed. [1]

The distinction does not make the result scientifically weak. A theory with independently constrained parameters can explain a known anomaly without having been adjusted freely to reproduce it. But its historical role differs from that of a measurement designed after a prediction was made. Those two forms of evidence should not be collapsed into a single story of repeated surprises.

Deflection of starlight near the Sun offered a different test. The 1919 eclipse measurements compared apparent stellar positions near the eclipsed Sun with reference positions. The result depended on photographic measurement, instrumental stability and the treatment of uncertainty. It was evidence about the behavior of light in the solar gravitational field, not a photograph of spacetime curvature itself. [1]

Special relativity and general relativity must also remain distinct. The former describes local nongravitational physics in inertial frames; the latter supplies a dynamical account of gravitation. Evidence for time dilation in a moving clock does not, by itself, choose general relativity over every competing gravitational theory.

2. Bringing gravitational frequency shifts into the laboratory

Pound and Rebka's 1960 experiment used resonant gamma-ray absorption to test a gravitational frequency shift over a vertical separation in a terrestrial laboratory. A controlled Doppler shift provided a way to compare an extremely small gravitational effect with an experimentally adjustable one. [2]

In the weak-field approximation, the fractional frequency difference has magnitude approximately gh/c^2 . Here g is gravitational acceleration, h the height separation and c the speed of light. The

sign depends on which location supplies the emitter and which the receiver. A photon received higher in the gravitational field is redshifted relative to the corresponding local transition.

For an illustrative separation of 20 meters, taking $g = 9.8$ meters per second squared and $c = 300$ million meters per second, the magnitude is approximately 2.18×10^{-15} . These rounded inputs illustrate the scale; they are not a reconstruction of the experiment's measurements. The experimental challenge is to separate such a shift from thermal motion, vibration and other effects on resonance.

The measurement tests a relation between gravitational potential and clock frequency. Its interpretation does not require treating the photon as a little Newtonian projectile with an ordinary rest mass. Nor does successful observation of this effect uniquely establish all the field equations of general relativity. Several metric theories share it. A precise result can therefore be decisive about one proposition while leaving others unresolved.

3. Measuring the time taken by a signal

In 1964, Irwin Shapiro proposed another test: a radar signal passing close to the Sun should take longer to complete its journey than the corresponding calculation without the relativistic gravitational contribution. The observable is a round-trip delay, inferred using a model of the positions and motion of the bodies involved. [3]

This changes what must be controlled. A deflection measurement compares directions; a ranging experiment compares times. Instrumental delay, orbital parameters and propagation through material along the path can matter. Measurements taken as the geometry changes help distinguish a gravitational signature from a fixed timing offset.

It is tempting to explain the predicted delay by saying that light simply slows down near the Sun. That phrase confuses coordinate descriptions with local measurement. In general relativity, a local freely falling observer measures the same vacuum speed of light. The total travel time concerns a path through a gravitational geometry and the clocks used to specify it. A coordinate speed can change without introducing a locally measured violation of special relativity.

4. Alternatives become part of the experimental design

By the 1960s and early 1970s, parametrized post-Newtonian methods made it possible to compare a range of weak-field gravitational theories through common parameters. Instead of asking only whether an observation agreed with Einstein, investigators could ask which combinations of parameters it restricted. Light propagation and orbital dynamics provided different combinations. [1]

Consider the logic of two hypothetical measurements. One constrains a combination of two unknown parameters; the other constrains a different combination. Each alone may allow many theories. Together they can exclude alternatives that survive either test separately. This is not a historical data set or a numerical fit. It explains why a coordinated program is more informative than a list of isolated successes.

The comparison is conditional on the framework. A theory outside its assumptions may require a different experimental description. Parameters do not automatically represent every imaginable deviation from general relativity. Their value is that they make a substantial, stated class of alternatives calculable and comparable.

5. What the period established, and what it did not

The period ending in 1975 should not borrow later successes to make its evidence look stronger. In particular, the later measurement of binary-pulsar orbital decay and the much later direct detection of gravitational waves do not belong among its completed tests. The relevant transformation had already occurred: increasingly precise experiments were being designed to separate gravitational possibilities.

Nor was this a transition from no evidence to perfect evidence. Early observations could be informative despite substantial uncertainty. Later instruments improved some controls while introducing different dependencies. The historical development is better understood through changing observables and error budgets than through a ceremony in which one famous experiment finally ended doubt.

The outcome was a new standard of explanation. A successful gravitational theory had to survive tests that probed different aspects of its structure, with alternatives and measurement assumptions made explicit. That standard strengthened general relativity while preserving questions it could not settle, including the relation between gravitation and quantum physics.

Related reading

BRK Article 009, “Quantum foundations become experimentally discriminable,” examines another transformation of theoretical disagreement into quantitative experimental alternatives.

References

- [1] Will, C. M. “The Confrontation between General Relativity and Experiment.” *Living Reviews in Relativity* 17, 4 (2014), introduction and sections on redshift and post-Newtonian tests. <https://doi.org/10.12942/lrr-2014-4>

- [2] Pound, R. V., and Rebka, G. A., Jr. "Apparent Weight of Photons." *Physical Review Letters* 4, 337–341 (1960). <https://doi.org/10.1103/PhysRevLett.4.337>
- [3] Shapiro, I. I. "Fourth Test of General Relativity." *Physical Review Letters* 13, 789–791 (1964). <https://doi.org/10.1103/PhysRevLett.13.789>