Relativity in Fundamental Astronomy
Proceedings IAU Symposium No. 261, 2009
S. A. Klioner, P. K. Seidelman & M. H. Soffel, eds.

doi:10.1017/S174392130999038X

The confrontation between general relativity and experiment

Clifford M. Will

Department of Physics, McDonnell Center for the Space Sciences,
Washington University, St. Louis MO 63130 USA
Gravitation et Cosmologie, Institut d'Astrophysique de Paris,
98 bis Bd. Arago, 75014 Paris France
email: cmw@wuphys.wustl.edu

Abstract. We review the experimental evidence for Einstein's general relativity. A variety of high precision null experiments confirm the Einstein Equivalence Principle, which underlies the concept that gravitation is synonymous with spacetime geometry, and must be described by a metric theory. Solar system experiments that test the weak-field, post-Newtonian limit of metric theories strongly favor general relativity. Binary pulsars test gravitational-wave damping and aspects of strong-field general relativity. During the coming decades, tests of general relativity in new regimes may be possible. Laser interferometric gravitational-wave observatories on Earth and in space may provide new tests via precise measurements of the properties of gravitational waves. Future efforts using X-ray, infrared, gamma-ray and gravitational-wave astronomy may one day test general relativity in the strong-field regime near black holes and neutron stars.

Keywords. gravitation, gravitational waves, relativity

Since the late 1960s, when it was frequently said that "the field of general relativity is a theorist's paradise and an experimentalist's purgatory" the field of gravitational physics has been completely transformed, and today experiment is a central, and in some ways dominant component. The breadth of current experiments, ranging from tests of classic general relativistic effects, to searches for short-range violations of the inverse-square law, to a space experiment to measure the relativistic precession of gyroscopes, attest to the ongoing vigor of experimental gravitation.

The great progress in testing general relativity during the latter part of the 20th century featured three main themes:

• The use of advanced technology. This included the high-precision technology associated with atomic clocks, laser and radar ranging, cryogenics, and delicate laboratory sensors, as well as access to space.

• The development of general theoretical frameworks. These frameworks allowed one to think beyond the narrow confines of general relativity itself, to analyse broad classes of theories, to propose new experimental tests and to interpret the tests in an unbiased manner.

• The synergy between theory and experiment. To illustrate this, one needs only to note that the LIGO-Virgo Scientific Collaboration, engaged in one of the most important general relativity investigations – the detection of gravitational radiation – consists of over 700 scientists. This is big science, reminiscent of high-energy physics, not general relativity!

Today, because of its elegance and simplicity, and because of its empirical success, general relativity has become the foundation for our understanding of the gravitational interaction. Yet modern developments in particle theory suggest that it is probably not the entire story, and that modifications of the basic theory may be required at some level.

However, any theoretical speculation along these lines *must* abide by the best current empirical bounds. Still, most of the current tests involve the weak-field, slow-motion limit of gravitational theory.

Putting general relativity to the test during the 21st century is likely to involve three main themes:

- Tests of strong-field gravity. These are tests of the nature of gravity near black holes and neutron stars, far from the weak-field regime of the solar system.
- Tests using gravitational waves. The detection of gravitational waves, hopefully during the next decade, will initiate a new form of astronomy but it will also provide new tests of general relativity in the highly dynamical regime.
- Tests of gravity at extreme scales. The detected acceleration of the universe, the observed large-scale effects of dark matter, and the possibility of extra dimensions with effects on small scales, have revealed how little precision information is known about gravity on the largest and smallest scales.

In this contribution to the Symposium, we reviewed selected highlights of testing general relativity during the 20th century and discussed the potential for new tests in the 21st century. We discussed the "Einstein equivalence principle", which underlies the idea that gravity and curved spacetime are synonymous, and describes its empirical support; solar system tests of gravity in terms of experimental bounds on a set of "parametrized post-Newtonian" (PPN) parameters; and tests of general relativity using binary pulsar systems. We also described tests of gravitational theory that could be carried out using future observations of gravitational radiation, and described the possibility of performing strong-field tests of general relativity. But because the content of this review has been published in various forms elsewhere, we did not submit a full article. For further discussion of topics in this paper, and for references to the primary literature, we encourage readers to consult *Theory and Experiment in Gravitational Physics* (Will 1993) and to the "living" review articles by Mattingly (2005), Psaltis (2008), Stairs (2003) and Will (2006).

Acknowledgements

This work was supported in part by the US National Science Foundation, Grant No. PHY 06-52448 and by the National Aeronautics and Space Administration, Grant No. NNG-06GI60G. We are grateful for the hospitality of the Institut d'Astrophysique de Paris, where this summary was prepared.

References

Mattingly, D. 2005, *Living Rev. Relativ.,* 8, 5 [On-line article] Cited on 1 June 2009, www.livingreviews.org/lrr-2005-5

Psaltis, D. 2008, *Living Rev. Relativ.,* 11, 9 [On-line article] Cited on 1 June 2009, www.livingreviews.org/lrr-2008-9

Stairs, I. H. 2003, *Living Rev. Relativ.* 6, 5 [On-line article] Cited on 1 June 2009, www.livingreviews.org/lrr-2003-5

Will, C. M. 1993, *Theory and Experiment in Gravitational Physics*, (Cambridge University Press, Cambridge)

Will, C. M. 2006, *Living Rev. Relativ.,* 9, 3 [Online article] Cited on 1 June 2009, www.livingreviews.org/lrr-2006-3

https://doi.org/10.1017/S174392130999038X Published online by Cambridge University Press