RELATIVITY IN FUNDAMENTAL ASTRONOMY:
DYNAMICS, REFERENCE FRAMES, AND DATA ANALYSIS

IAU SYMPOSIUM No. 261

COVER ILLUSTRATION: SERGEI A. KLIONER

This is an artist view of the research field of Applied Relativity. The picture shows the basic pillars of Applied Relativity, directly related to the main subjects of the Symposium: theoretical formulation of reference frames and theoretical (analytical and numerical) modelling of dynamics of celestial bodies and light rays, and the aspect of data processing.

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Preface

The history of Einstein's theory of gravity (General Relativity Theory, GRT) can roughly be divided into three epochs. The first epoch started with Einstein's classical papers on the foundation of "General Relativity" (end of 1915), which soon opened up a vast opportunity for mathematicians and mathematical physicists. It was mainly a mathematically oriented discipline. The exceptions were related with the very first experimental tests of GRT. The central problem of celestial mechanics of the 19th century, namely Mercury's anomalous perihelion precession of 43″ per century, could be explained.

The first measurements of the light deflection by the gravitational field of the Sun during the British expeditions to Sobral (Brazil) and Principe (Gulf of Guinea), taking photographic pictures of the solar vicinity during the solar eclipse on the 29th May, 1919, made Einstein famous.

The situation changed drastically in the second phase of testing, after about 1960. New technological innovations and techniques (atomic clocks, laser reflectors on dedicated satellites and on the lunar surface, radio interferometry, microwave techniques, etc.) not only allowed precise testing of the foundations of any physically reasonable theory of gravity (equivalence principles, gravitational redshift, etc.) and precise solar system tests of GRT, but also led to the rapid development of *relativistic astrophysics*, dealing with fantastic objects such as quasars, pulsars, black holes, gravitational lenses, and even the birth of our entire Universe some 14 billion years ago. The discovery of the binary pulsar PSR 1913+16 by Hulse and Taylor in 1974 revealed a new arena where theories of gravity can be tested. The existence of gravity waves, for the first time in history, was indirectly demonstrated. In parallel with that progress on the observational side, Kenneth Nordtvedt and Clifford Will came up with a parametrized post-Newtonian formalism that covers the post-Newtonian approximation of a great number of alternative theories of gravity. A certain set of PPN parameters, that can be determined experimentally together with realistic error bars, distinguishes these various limits. So far Einstein's theory of gravity has passed every experimental test with flying colors.

In the third present epoch, Einstein's theory has to be considered as an integral part of classical physics; nowadays it is employed to solve technologically oriented problems. Meanwhile, the stability of atomic clocks is of the order of a few times in 10^{-16}, with revolutionary consequences for the problem of navigation (GPS, GLONASS, etc.). VLBI measurements, as a basis for our present celestial reference system (ICRS) and the field of global geodynamics, presently aim at mm accuracies. Laser measurements to selected satellites (SLR) and retroreflectors on the lunar surface (LLR) have accuracies in the cm range. Consequently, solar system ephemerides, theories for time dissemination, clock synchronization, global geodynamics, light propagation, etc. have to be described in the framework of Einstein's theory of gravity. GRT has become the basis for astrometry, celestial mechanics, and metrology.

In the field of astrophysics, objects, that had been considered to be very exotic originally, such as gravitational lenses, pulsars, neutron stars, or black holes, have become quite common objects in the sky (though an ultimate proof of the existence of black holes is still overdue). Pulsars are being investigated as precise clocks that might provide an independent source of precise and stable time. Soon we might be in a position to test the theoretical 'no hair theorem' of black hole physics experimentally. After the first doubly imaged quasar was discovered in 1979, gravitational lensing became an observational science that has contributed significantly new results in areas as different as the cosmological distance scale, mass determination of galaxy clusters, physics of quasars, searches for dark matter, etc. Our present cosmological standard model based on GRT is now supported by numerous observations, especially those related with the anisotropies of the Cosmic Microwave Background Radiation. Detailed measurements of these anisotropies (e.g., by WMAP) lead to an observational determination of the basic cosmological parameters, including the age of the entire Universe.

Today, Applied General Relativity is a broad interdisciplinary field with various experts in different niches. Often they come from different branches of physics and astronomy and experience difficulties to communicate with each other because of their different languages. For that reason we felt the importance to bring such experts together, and to modify the various languages a bit in order to simplify communication with each other. We hope that our Symposium has contributed to this ambitious goal at least a little bit.

Sergei A. Klioner, P. Kenneth Seidelmann and Michael H. Soffel (Proceedings Editors)

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