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Gyros, Clocks, Interferometers...: Testing Relativistic Gravity in Space



Springer

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Preface

Nowadays, Experimental Gravitation is one of the exciting areas in modern physics. Many important experiments have entered their final state of realization: In 2001 the interferometric gravitational wave detectors will start to collect data, in May 2002 Gravity Probe B (Stanford orbiting gyroscope experiment) will be launched, and, in 2005, STEP (the Satellite Test of the Equivalence Principle) is planned to be put in orbit. All these experiments will give new momentum to the field of experimental gravitation and, of course, to the development of theoretical concepts in gravity.

Besides this, the development of many new devices for carrying through high-precision measurements will open up new areas for testing the gravitational interaction. New atomic *clocks*, such as the atomic fountain clock, for example, or clocks which will be based on Bose–Einstein condensates, will lead to an increased precision, giving better results of tests of, for example, the gravitational red shift, or will enable the measurement of gravitomagnetic effects for clocks. Also, new quantum devices like atom *interferometers* or interferometers with Bose–Einstein condensates will give much better results while probing the gravitational field. And, last but not least, clocks will have an application in establishing a global reference system which is used for the GPS (Global Positioning System) and for telecommunication.

From the theoretical point of view all these experiments are highly interesting and the new results will stimulate the effort of unifying the four interactions and/or finding a consistent combination of gravitation theory and quantum theory, i.e., a quantum gravity theory. It is a general feature of such generalized theories of gravity that extra scalar interactions emerge accompanying the gravitational interaction. As one consequence they lead to a violation of the Equivalence Principle. Moreover, anomalous spin interactions may arise in that context. Therefore, tests of gravity may be at the same time tests of our microscopic view of the world.

Experiments are designed for testing the predictions of a theory as well as for testing the foundations of theories. In these proceedings both aspects are represented. The Lense–Thirring effect and gravitational waves are two of the main predictions of General Relativity which have not yet been confirmed directly or with convincing precision. As far as the foundations of General Relativity are concerned, we deal with the test of the Equivalence Principle which is at the very heart of the geometric nature of General Relativity. This principle is character-

istic for this kind of interaction. Other topics in this volume are experiments with clocks that measure the universality of the gravitational red shift. A violation of this universality implies the existence of more than one gravitational interaction. In addition, since the most precise clocks are atomic clocks, this class of experiments also yields information about the action of gravity in the quantum domain. Therefore, the application of new quantum-based devices, like atomic interferometers, has been examined for measurements of gravitational interaction. These and other devices seem to be very promising for increasing the experimental precision considerably. Thus, the effects of gravitation on quantum systems with spin are part of these proceedings. All these attempts will provide a better experimental foundation for the theory of gravity.

Accordingly, our meeting about *Gyros, Clocks, Interferometers, ... : Testing General Relativity in Space* held from 21 to 27 August 1999 in Bad Honnef and these proceedings are devoted to these topics:

- The Lense–Thirring effect
- The detection of gravitational waves
- Testing the Equivalence Principle
- Clocks and rods in gravitational fields
- Quantum tests of gravity
- Electromagnetic field and gravity

We want to present a review of the status of experimental gravity at the beginning of the 21st century. In doing so, we first tried to give a theoretical understanding of the various effects followed by reports about the status of the various experimental projects. We got the impression that this combination of theoretical and experimental talks gave a more complete picture of what is going on and contributed to the mutual understanding of theoreticians and experimentalists.

Finally, we would like to express our gratefulness to the *WE–Heraeus Foundation* for financing this meeting and the *Deutsche Forschungsgemeinschaft* (DFG) for giving support to many of our colleagues from Eastern Europe.

Konstanz and Düsseldorf, Stanford, Cologne
October 2000

Claus Lämmerzahl
Francis Everitt
Friedrich W. Hehl

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List of Abbreviations

ALLEGRO	Gravitational bar detector, USA
ASTRE	Accelerometre Spatial TRIaxial Electrostatique
ASTROD	Astrodynamical Space Test of Relativity using Optical Devices
AURIGA	Gravitational bar detector, Italy
AXEL	AXial Experiment at Low temperature
CHAMP	CHAllenging Micro-satellite Payload for geophysical research and application
CODATA	Committee on Data for Science and Technology
CWDB	Close White Dwarf Binaries
EEP	Einstein Equivalence Principle
EP	Equivalence Principle
EXPLORER	A gravitational wave antenna located at CERN in Geneva
GAIA	Global Astrometric Interferometer for Astrophysics
GEO 600	German-British gravitational wave interferometer in Hannover
GOCE	Gravity and Ocean Circulation Explorer
GP-B	Gravity Probe B
GRACE	Gravity Recovery And Climate Experiment
HIPPARCOS	HIGH Precision PARallax COLlecting Satellite
HYPER	HYPER sensitive cold atom interferometry in space
IPLR	InterPlanetary Laser Ranging
LAGEOS	LAser GEOdynamics Sattelite
LIGO	Laser Interferometer Gravitational wave Observatory
LISA	Laser Interferometer Space Antenna
LLI	Local Lorentz Invariance
LLR	Lunar Laser Ranging
MOT	Magneto-Optical Trap
MICROSCOPE	MICRO-Satellite à trainée Compensée pour l'Observation du Principe d'Equivalence
NAUTILUS	Gravitational bar detector at Laboratori Nazionali di Frascati, Italy
PPN	Parametrized Post-Newtonian approximation
SORT	Solar Orbit Relativity Test
SQUID	Super conducting QUantum Interference Device
STAR	Space Three-axis Accelerometer for Research
STEP	Satellite Test of the Equivalence Principle
TAMA300	Japanese gravitational wave interferometer
VIRGO	French-Italian gravitational wave interferometer in Pisa
VLBI	Very Long Baseline Interferometry
WEP	Weak Equivalence Principle
rf	radio frequency
rms	root mean square

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