Current and Future Tests of General Relativity

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General Relativity (GR) holds a special place amongst all fundamental theories of physics: on one hand, it is the theory of all gravitational phenomena; on the other hand, it is also a theory of spacetime. However, the structure of spacetime enters all other physical theories of interactions at the most fundamental level. Hence, as a matter of principle, the status of GR cannot be thought of as isolated from the rest of fundamental physics. According to GR, gravity is not just one amongst four independently rooted interactions. If, under certain physical conditions, GR turns out to fail, this will inevitably also effect the rest of physics. Testing GR up to the most extreme conditions imaginable is therefore not just an end in itself, it also means probing the very foundations of physics. For further discussion on the present and future perspectives on gravitation and cosmology, see the Special Issue celebrating the centennial of GR in this journal, in particular [1,2] and references therein.

In this Special Issue we did not attempt to collect a representative cross-section of all ongoing research regarding all tests of GR. This would indeed have been a formidable task, and at the completion of which we would probably have to revise its beginning due to the already very fast and still accelerating developments in observational and experimental techniques. In addition, there already exist impressive collections and discussions covering most of the research up to about ten years ago, such as [3]. Rather, the task we set ourselves was to look at certain typical questions via selected papers by outstanding contributors. This may be looked upon as regarding cutting-edge research through a magnifying glass.

Our collection of six papers contains three reviews on a broader scale and three contributions that focus on more particular issues. In the order of submission they are:

1. “Revisiting the 2PN Pericenter Precession in View of Possible Future Measurements” by Lorenzo Iorio (19 pages);
2. “Gravity Tests with Radio Pulsars” by Norbert Wex and Michael Kramer (38 pages);
3. “Benefit of New High-Precision LLR Data for the Determination of Relativistic Parameters” by Liliane Biskupek, Jürgen Müller and Jean-Marie Torre (13 pages);
4. “On the 2PN Pericentre Precession in the General Theory of Relativity and the Recently Discovered Fast-Orbiting S-Stars in Sgr A*” by Lorenzo Iorio (12 pages);
5. “On the 2PN Periastron Precession of the Double Pulsar PSR J0737–3039A/B” by Lorenzo Iorio (12 pages);
6. “Testing General Relativity with Gravitational Waves: An Overview” by Naderi Varium Krishnendu and Frank Ohme (21 pages).

Research into radio pulsars has been, and will be for a long time to come, one of the most fruitful, most rich, and also most complex part of physics, involving essentially all of its disciplines [4]. Much new physics, not only gravitational, can be expected from pursuing this line of research, but the computational efforts required are enormous.

Gravity-wave research has recently undergone a dramatic transformation process from mere detection into a powerful observational tool and thereby one of the main supporting pillars in a new era of multimessenger astronomy [5]. It currently dominates observational gravity research worldwide and will almost certainly lead to many unexpected new insights

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into early cosmology as well as the physics of compact objects, in particular black holes and neutron stars.

Despite the spectacular aspects of the areas mentioned, which are often exclusively mentioned in public talks and also as “selling points” for gravity research, one should not forget that solar system and near-Earth gravity research is by no means closed, and that GR is also becoming a tool for studying the Earth’s environment. Relativistic Geodesy and inertial sensing are closely linked to GR and rely on its predictions, and can, conversely, be used for high-precision tests of GR [6]. Present and future perspectives for further solar-system tests are discussed in [7].

However, last but not least, it needs to be mentioned that eventually everything depends on getting the details right. The “grand picture”, beautiful as it may appear from a distance, should not be trusted unless all details have been checked independently. Calculations based on post-Newtonian approximation schemes are central but delicate and need to be cross-checked independently [8–10]. How much goes into this, and how much can be drawn from it, can be nicely exemplified by the pericenter precession that more than 100 years ago led to the first stunning success of GR.

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