Department I

The History of Quantum Gravity Research

In 1930, Leon Rosenfeld was the first physicist to attempt a quantization of the gravitational field.

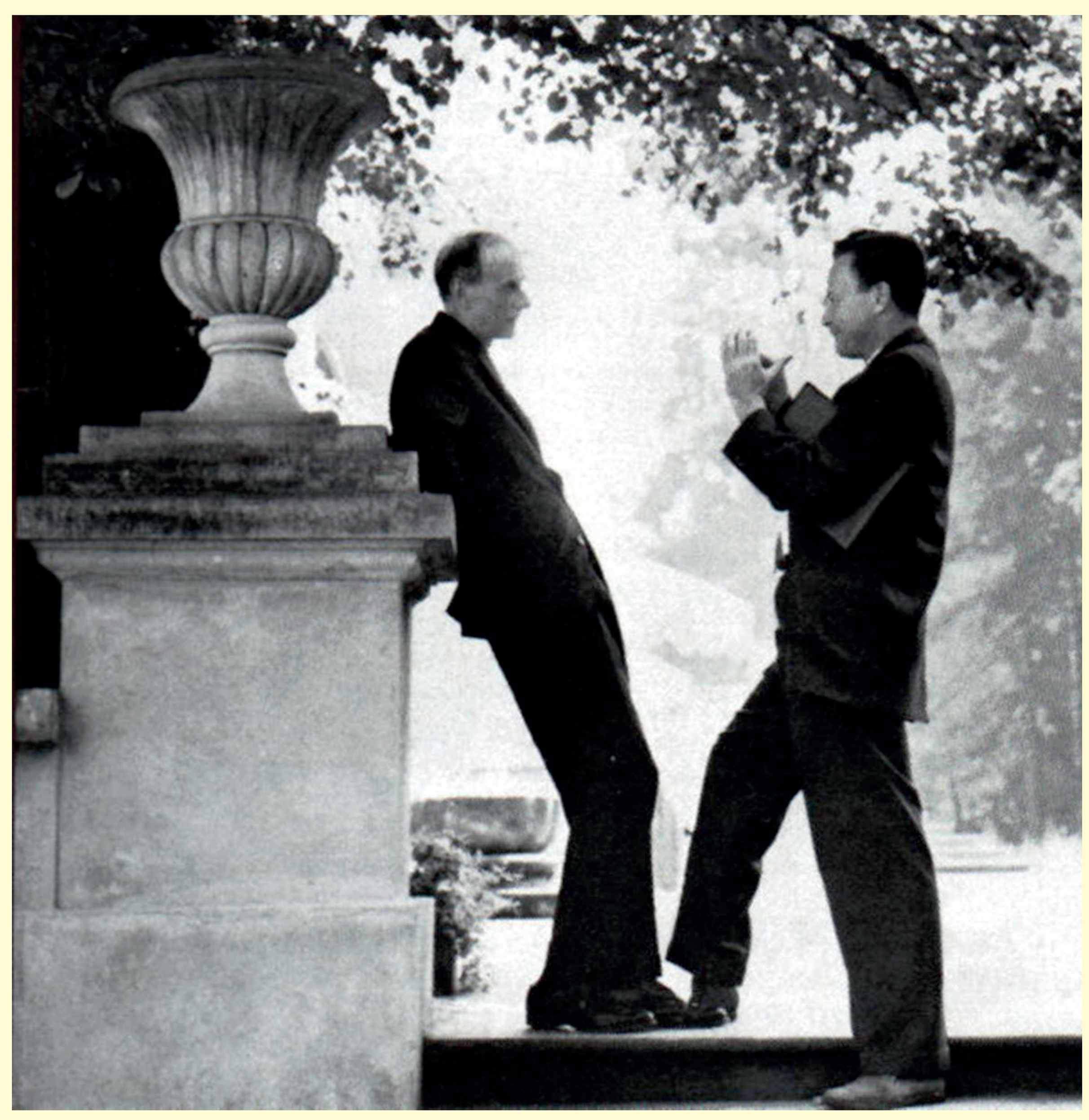
The project was established with the aim of studying the borderline problems at the interface of quantum theory and (general) relativity, which began to capture the attention of physicists after those two theories had emerged from similar conceptual clashes within classical physics, and from the consequent restructuring of the knowledge it contains. The search for a successful theory of quantum gravity that can bridge this divide has been going on for almost a century, for a long time entirely free from any empirical manifestations of the divide. This search offers a unique opportunity to test and refine dynamical models of knowledge development.

It had already been observed in the study of quantum mechanics that classical mechanics itself was in fact developing while and even because of the genesis of quantum mechanics. Similar developments could be observed in the context of quantum gravity research, where the difficulties at their boundaries led to reflective reorganization within the two maturing theoretical frameworks, quantum field theory and general relativity. Thus, for instance, in 1930 while in effect creating a space-time background-independent formalism that would be amenable to quantization, Léon Rosenfeld provided both a justification and a theoretical basis for tools that were then being deployed in constructing quantum electrodynamics (Salisbury). The development of classical constrained Hamiltonian dynamics by Rosenfeld, Tsung-Sui Chang, Peter Bergmann, and Paul Dirac also represents an internal theoretical consolidation process in classical relativity that was motivated by the perceived need to create a suitable framework for implementing general covariance in quantum gravity (Renn, Rickles, Salisbury). These studies draw in part on a series of interviews conducted by Dean Rickles and Don Salisbury in March 2011 with several key contributors in this development in the 1950s and 1960s. The disputed meaning of observables in general relativity features in much of this work.

Wolfgang Pauli and his assistant Markus Fierz, who, in 1939, discovered a non-geometric approach to quantum gravity.

Similarly, a study has revealed how the development of a covariant formulation of quantum gravity closely followed and interacted with developments both in general relativity and, even more important, in quantum field theory, where Richard Feynman's research in quantum gravity led to the resolution of a difficulty (the unitarity problem) in nuclear field theory. This close association with developments in quantum field theory, which ensured that the theory was always well-defined (as opposed to other, more programmatic approaches), led to the first formal proof of the incompatibility of quantum theory and gravity in 1974 (Blum).

The group's research has been accompanied by two workshops on the Historical Roots of Quantum Gravity Research, where relevant sources were identified, studied, and discussed in an interdisciplinary group of ten (2010, at Caltech) and twenty-five (2011, at the MPIWG) researchers, respectively. Among the discussed sources was the report of the 1957 Chapel Hill conference, arguably the event where discussions on quantum gravity entered the American physics mainstream. In 2011, the original report, compiled by Cécile M. DeWitt, was converted into a book (Rickles). A further volume of early sources of quantum gravity based on the discussions of the workshops and accompanied by a historical introduction is in preparation (Blum, Rickles).



Paul Dirac and Richard Feynman discussing behind Jablonna palace near Warsaw, Poland, at the epochal 1962 conference.

A second focus of the group's research has been an in-depth conceptual study of the interfaces between quantum theory and general relativity, especially addressing the question of how the discrepancies between the two theories were and are manifested in some of their key notions. The first major investigation in this direction is concerned with the equivalence principle and the reinterpretations of the classical notion of action, which played important roles as heuristic principles in the development of general relativity and quantum theory, respectively (Blum, Renn, Salisbury, Schemmel, Sundermeyer).

A similar conceptual approach led to a re-evaluation of the dominant contemporary canonical approach to quantum gravity, as a consequence of recent progress in the understanding of the symmetries generated by constraints in the classical canonical formalism (Renn, Salisbury).

Reorganizing Knowledge in Modern Science

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