Description for the general public

When Stephen Hawking presented his famous derivation of thermal particle creation by black holes for the first time in 1975, his report began with the sentence: “Although there has been a lot of work in the last fifteen years, I think it would be fair to say that we do not have a fully satisfactory and consistent quantum theory of gravity”. It is still fair to say this, especially for no fully satisfactory quantum theory of gravity exists that would enable us to compute effects of physical interest, such as what ultimately happens to a black hole that is emitting Hawking radiation. Still, much insight has been gained in the intervening years, and the level of our understanding has gone up. In particular, following the discovery of the anti-de Sitter/conformal field theory correspondence, there is now universal agreement that progress hinges on a deep understanding of the theory whose quantum version is being sought: general relativity.

Quantum physics and general relativity are the two main intellectual developments in physics both emerging almost simultaneously during the first decades of the twentieth century. Since the beginning there is a natural desire to bring the underlying significantly different concepts closer to each other. It sound to be logical that we should aim to construct a quantum theory of gravity which has Einstein's theory as its classical limit. Canonical quantum gravity is one of the most natural choice as a theoretical framework within which such a programme may be carried out.

Canonical quantum gravity has a long history and it has been used extensively in context of various conceptual issues including the problem of time and the possible meaning of a quantum state of the entire universe. However, in the approaches as yet applied there are unavoidable technical difficulties originating from the fact that Einstein's equations are highly nonlinear, that diffeomorphism invariance invokes one of the most difficult gauge freedom in physics, that the constraints are non-linear and, on top of these, that we lack a unique time parameter (a troublesome situation referred also as the problem of time). All these difficulties originate from the mere fact that the spacetime metric has two roles in Einstein’s theory. From dynamical point of view it could be more rewarding to use some less redundant representation of the gravitational degrees of freedom, whereas most of the fundamental physical or mathematical concepts such as the lapse of proper time, measure of volume, area, or angles between directions, requires the use of the full spacetime metric.

My research proposal should be seen in this generic context. It aims to carry out investigations on two closely related aspects of canonical quantum gravity: the problem of time and the identification of the true degrees of freedom of gravity. Both of these fundamental issues requires the use of the most recent results of the evolutionary aspects (many times also referred as the Cauchy problem) of Einstein’s theory. In this context I intend to use some of my recent observations concerning the constraint and evolution equations in the classical theory. These preliminary results opened up new passages in the Cauchy problem of general relativity. In particular, these new results enable us to make significant step forward to the isolation of the true physical degrees of freedom of Einstein's theory, a problem at the foundation of the canonical quantization programme, but where progress so far has been slow. To indicate the importance of progresses in this direction one may recall the following statement from Wald’s famous book “... no way singles out precisely which functions (i.e., which of the 12 metric or extrinsic curvature components or functions of them) can be freely specified, which functions are determined by the constraints, and which functions correspond to gauge transformations. Indeed, one of the major obstacles to developing a quantum theory of gravity is the inability to single out the physical degrees of freedom of the theory.”

Clearly the above indicated research project has many facets and one should not expect to complete the quantization program of gravity within the given time frame of the proposed research program. Nevertheless, I am convinced that two years of dedicated joint work integrating efforts of world class leaders of the involved fields will lead to notable progress. The interdisciplinary features of the proposed research and that of the applied techniques, on the one hand, enhance the interrelation of the involved areas. On the other hand, the success of the program could also yield simultaneous stimulation for each of the individual fields, including the Cauchy problem, the classical canonical formulation of general relativity and other non-linear theories or the canonical quantization of fields in various theories. I believe that any progress made using the canonical quantization setup is of obvious interest. From this point of view it is important to remark that, despite the indicated difficulties, the mathematical framework of canonical quantization is in some ways better understood than any other attempt in quantizing gravity. Therefore, the introduction of some prosperous new ideas would shed light on many of the so far unsolved issues and important progress could be made in various directions. All the anticipated new developments should invoke stimulation for the scientific community but presumably will also have considerable impact on the society as a whole.