Self-Subsisting Structures in Quantum Gravity

The main goal of the research is to try to answer some fundamental questions about the nature of space and time, such as "do space and time exist?" and "are space and time made up of tiny quantum pieces, as matter seems to be?". In order to find a plausible answer to these questions, we rely on science, and thus we look at what modern physics has to say about that. We already know from Einstein's general theory of relativity that gravity is deeply linked to space and time, to the point that spatial and temporal phenomena, such as for example the ticking of a clock, are not only influenced by, but are by themselves a manifestation of the gravitational field. Now, if we assume that gravity is a field, just like the electro-magnetic one, then it is very likely that, if we look at it very closely, it will show the strange behavior typical of quantum systems. But, if gravity and space and time are one and the same thing, then the above reasoning entails that space and time behave at short scales as quantum entities. According to the most promising programs for straightforwardly quantizing the gravitational field of general relativity, this is in fact the case.

All the theoretical implementations of quantum general relativity so far agree to some extent in delivering a short-scale picture of physical space as a quantum superposition of structures with very weak (or even absent) spatial connotations –being them either field magnitudes or atoms in a literal sense. This fact renders entirely mysterious how classical space can emerge from a quantum "foam" of different and mutually exclusive arrangements of parts that might even lack any spatiality. Another open problem in quantum general relativity is that many quantization procedures lead to a static, timeless equation governing the behavior of the fundamental elements of the theory –whatever they are. This might hint at the fact that, at the fundamental level, time simply does not exists or, less radically, that temporal degrees of freedom are either hidden inside the formalism or were cut away from the quantum formalism due to a mistaken quantization procedure.

The project will first analyze in depth the issue of elaborating an account of what a superposition of quantum-gravitational "bits" really amounts to. With this respect, an approach towards quantum physics known as *primitive ontology* will be adopted. The main tenet of this approach, which dates back to the French physicist Louis de Broglie, is that quantum features such as superpositions are not in fact real, but just a consequence of an incomplete description of quantum systems. What quantum physics lacks, in fact, is an "ontological bedrock" made of objects with a well-defined position at each time. Once a dynamical law that describes the behavior of this primitive ontology is provided, the resulting theory is capable of recovering the same empirical predictions of standard quantum theories. It is then clear that, by showing that this approach can be safely adopted also in quantum general relativity, the problem of superpositions of quantum-gravitational structures would be avoided. However, the problem is now shifted to provide a coherent account of structures that, obviously, are not in space and time. The project will attempt to solve this issue by resorting to a metaphysical stance known as *ontic structural realism*. This position holds that fundamental entities are, in fact, structures, that is, networks of objects that stand in some physical relation. The important point is that, in a structural realist framework, objects do not need to be individuated with respect to their position in space but, rather, it is sufficient to specify their "position" in the relational structure. The research will provide a thorough characterization of what an arrangement of quantum-gravitational "bits" is by elaborating a metaphysical account of notions such as "object", "relation", and "structure", which is able to accommodate these concepts in a context where there is no external space and time that can confer a straightforward meaning upon them. The research will also investigate how these "self-subsisting" structures evolve dynamically in a way such that the emergence of our everyday space and time can be explained.

Asking how space and time look at the quantum scale is a legitimate and, indeed, intriguing question for physicists, philosophers, and anybody interested in the ultimate nature of reality. The prima facie picture delivered by quantum gravity of a fundamental reality being basically "spacetimeless" represents a radical departure from the intuitive, manifest image of the world we are accustomed to, which then pushes us to clarify and sharpen this picture in order to explain how our everyday conception of space and time can be recovered from the rather different image of the world provided by modern physics.