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Modern physics relies on two distinct fundamental theories, General Relativity and Quantum Mechanics. Both describe on one hand macroscopic and cosmological phenomena such as gravitational waves and black holes and on the other hand microscopic phenomena as superfluidity or the spin of particles. The unification of these two theories remains, so far, an unsolved problem. Interestingly, candidate Quantum Gravity theories predict a violation of the principles of General Relativity at different levels. It is, therefore, of a timely interest to detect violations of these principles and determine at which level they occur.

Recent proposals to perform Einstein Equivalence Principle tests suggest a dramatic performance improvement using matter-wave atomic sensors. In this context, the design of the input states with well defined initial conditions is required. A state-of-the-art test of the universality of free fall (UFF) would, for example, require a control of positions and velocities at the level of 1µm and 1µm.s^{-1}, respectively. Moreover, size-related systematics constrain the maximum expansion rate possible to the 100 µm.s^{-1} level. This initial engineering of the input states has to be quite fast, of the order of few hundred ms at maximum, for the experiment’s duty cycle to be metrologically-relevant.

In this thesis, fast transport and manipulation protocols of Bose-Einstein condensates (BEC) with an atom chip devices are proposed relying on reverse engineering techniques with shortcut-to-adiabaticity protocols. This technique provides the possibility to engineer transport ramps with specific desired initial and final conditions. The robustness of such an implementation was presented in the context of a realistic experimental configuration. Optimized sequences, involving the characterization of the excited modes of the BEC after transport have been proposed to constrain the size of the BEC to few hundred microns after few seconds with a expansion energy as low as few tens of pK. Such protocols have been successfully transferred to the microgravity Quantus-2 drop tower experiment, to the sounding rocket space BEC mission Maius-1 and to the cold atom laboratory (CAL) on board of the International Space Station.