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High Precision Quantum Tests of the Equivalence Principle to Distinguish Between Equivalent Gravities

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Recent theoretical advancements in gravitational physics, particularly within the framework of the Geometric Trinity of Gravity, challenge the traditional assumptions on spacetime underlying General Relativity (GR). The Geometric Trinity comprises GR, grounded in the curvature of spacetime; the Teleparallel Equivalent of GR (TEGR), formulated in terms of torsion; and the Symmetric Teleparallel Equivalent of GR (STEGR), built up on nonmetricity. Recent results show that GR, TEGR and STEGR are dynamically equivalent in many different aspects but not exactly in everything. In particular, the Equivalence Principle (EP) can be recovered in TEGR and STEGR, but it is not at the foundation of them as in GR. Therefore, the central argument of this work shows that, given the equivalence between GR, TEGR and STEGR in non-trivial multiple predictions, and given the fact that the EP is not necessary for TEGR and STEGR in order to have the same predictive power, the EP should not be considered as fundamental, but emergent. Moreover, many open conceptual difficulties which are consequences of the EP can be addressed in the framework of the Geometric Trinity. In conclusion, this argument shows that current precision levels of EP tests should not discourage further research, especially at quantum level. Therefore, the incoming experiments of free falling with ultra-cold atoms could be the quintessential method to explore the very foundations of our understanding of gravity and spacetime. In Florence in particular, we are designing a very high precision test of the EP with a gradiometer with squeezed Strontium atoms.

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