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Precision clockwork for optical clock operation at the 1E-19-level accuracy

Optical frequency standards have achieved fractional stabilities of a few parts in 1E19 [1], with accuracies approaching and soon reaching the same level [2]. Furthermore, extraordinary progresses have been made on rendering these complex apparatuses transportable [3,4], such to enable their use as quantum sensors for testing fundamental physics and General Relativity [5].
In order to construct atomic clocks and generate timescales with optical frequency standards, we have contributed in advancing the spectral purity, stability and relative accuracy of optical frequency combs and the extraction of the lowest phase noise photonic microwave signals demonstrated so far [6]–[8]. These advances aim to support the comparisons via frequency ratio measurements of 18-digit accurate optical frequency standards [9]. Additionally, these achievements allow to construct accurate clockworks capable of porting exquisite optical fidelity down to the microwave domain. The phase-coherent transfer of the optical frequency standard´s precision and accuracy to the electrical signals is necessary to permit access to these fidelities by conventional electronics.
We will cover the path towards the realization of these ultra-low noise clockworks, and illustrate their engineering, now allowing us to demonstrate 1E-19-level stability and relative accuracy also on transportable systems. These achievements are key for constructing practical optical clocks and quantum sensors which are now conceived as deployable measurement tools, and paving the way to an optical SI-second redefinition.

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