Twisted-light field-induced spectroscopy of forbidden optical transitions with application to SU(2) hyper-clocks:

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In time and frequency metrology, an atomic clock is a quantum sensor which produces, through a local oscillator (LO), some interference signals that are locked to a 2-level quantum system generating by electronic feedback stability and accuracy of the LO. Technically, our two-level system or qubit is probed by a sequence of electromagnetic pulses which generate some Pauli-rotations of the qubit inside a SU(2) space also called a Bloch sphere.

The hyper-clock is a new generation of robust optical frequency standards based on Ramsey spectroscopy using sophisticated Pauli-rotations through a sequence of composite laser pulses eliminating the light-shift, one of the systematic correction related to the clock frequency measurement [1] . This method has been experimentally demonstrated for the first time in 2016 using the octopole E3 transition of a single trapped ion $^{171+}$Yb at the PTB in Germany, leading to a reduction by more than 3 orders of magnitude of the light-shift and making this optical clock one of the best accurate frequency standards at that time. Today, new protocols have been identified to be more robust against light-shift associated to decoherence in SU(2) quatum systems [2].

We present our recent work on twisted–light (TL) inducing atomic spectroscopy of forbidden clock transitions with bosonic isotopes of Ca, Mg, Yb, Sr, Hg and Cd. Two potential implementations are investigated with the forbidden clock transition 1S0←→3P0 and the magnetic quadrupole 1S0←→3P2 transition of Sr 88. The twisted-light probe beam is highly focused where longitudinal electric and magnetic fields are very strong along the laser axis propagation which opens the 1S0←→3P0 clock transition by a E1M1 two-photon process. The magnetic quadrupole (M2) 1S0←→3P2 transition is driven by the spatial distribution of gradient of electromagnetic fields related to the twisted-light through the simultaneous action of orbital angular momentum (OAM) and spin angular momentum (SAM). Some of these contributions have vanishing electric and magnetic field components along the beam axis center strongly reducing the light-shift perturbation while gradients of them are very large to excite the magnetic quadrupole moment. All residual electromagnetic multi-polar corrections to the clock transition frequency generated by off-resonant atomic states and synchronized with the application of the TL laser probe are eliminating by SU(2) hyper-clock interrogation protocols.

Refs:[1] T. Zanon-Willette, D. Wilkowski, R. Lefevre, A.V.Taichenachev and V.I. Yudin, SU(2) hyper-clocks:Quantum engineering of spinor interferences for time and frequency metrology, Phys. Rev. Research 4, 023117 (2022).

[2] T. Zanon-Willette, *et Al*, Composite laser-pulses spectroscopy for high accuracy optical clocks: a review of recent progress and perspectives Rep. Prog. Phys. 81 094401 (2018).