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Cavity-Enabled Spin Squeezing for a Quantum-Enhanced Atomic Clock[1]

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For the past decade, the stability of microwave atomic clocks has stood at the standard quantum limit, set by the projection noise inherent in measurements on ensembles of uncorrelated particles. We have now, in proof of principle, surpassed this limit by operating with atoms in a particular type of entangled state called a "squeezed spin state." The generation of non-classical spin correlations in a dilute cloud of atoms is facilitated by an optical cavity, which allows for strong collective coupling of the atomic ensemble to a single mode of light. Since the light exiting the cavity is entangled with the atoms, an appropriate measurement performed on the light field can project the atomic ensemble into a squeezed spin state. We have demonstrated 3.0(8) dB of spin squeezing by this method of quantum non-demolition measurement. We have further developed a new method, cavity feedback squeezing, which uses the light field circulating in the resonator to mediate an effective interaction among the atoms. The states prepared by cavity feedback are intrinsically squeezed by up to 10(1) dB and detectably squeezed by up to 5.6(6) dB. Applied in an atomic clock, they produce an Allan variance 4.7(5) dB below the standard quantum limit for averaging times of up to 50 s.

[1]Ph.D. thesis, Massachusetts Institute of Technology. Collaborators: Ian Leroux and Vladan Vuletic (thesis advisor).