

# Measurement beyond standard quantum limit realized with nitrogen-vacancy centers in diamond

August 31 2021, by Liu Jia

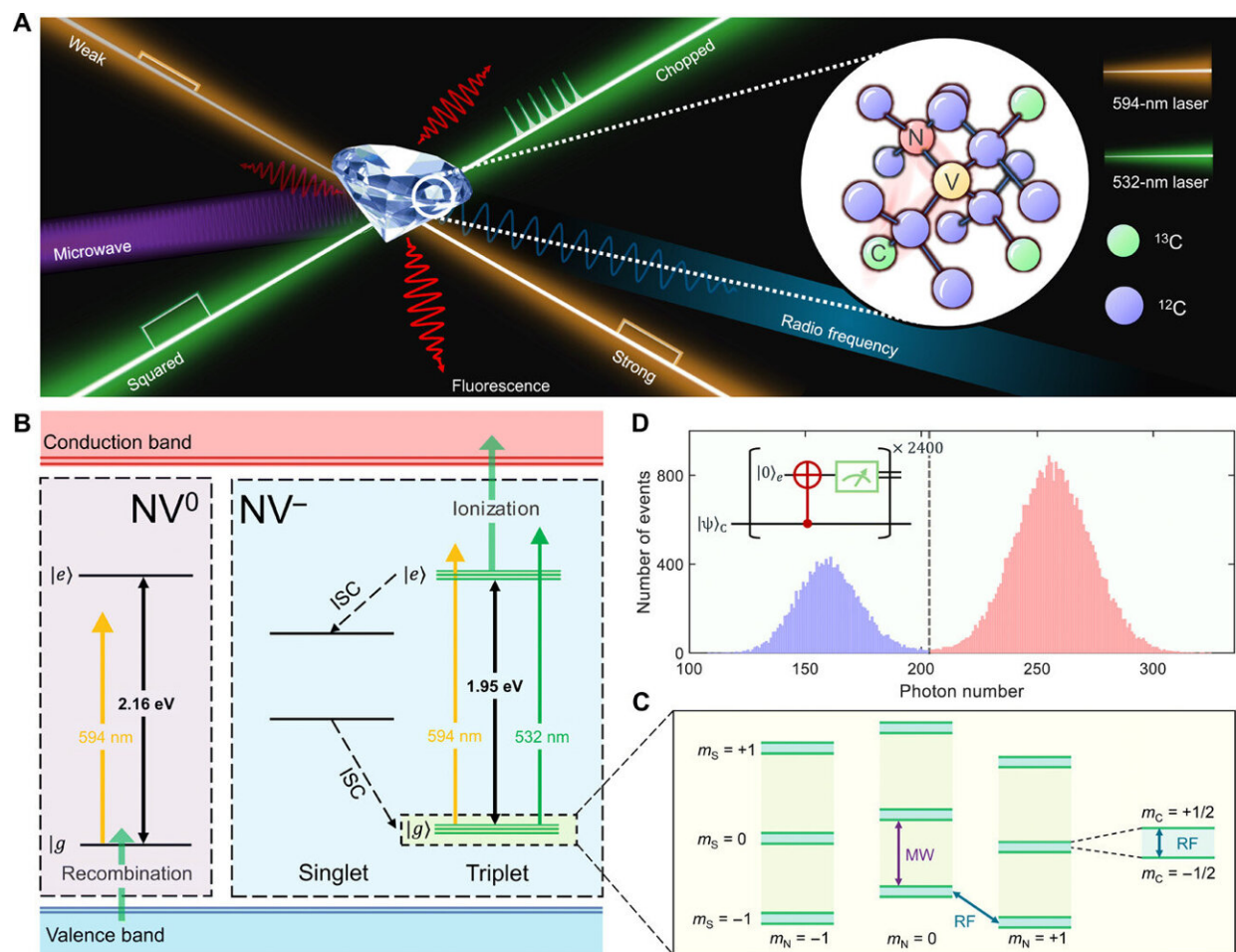


Fig. 1 Dynamics and control of a single NV center. (A) Diagram of a single NV center in diamond. It is driven by various laser beams and coherently controlled by MW and RF pulses. Squared: squared 532-nm green laser for readout of the NV electron spin and mixing charge states; chopped: chopped laser sequence for

a better polarization of the electron spin without destroying charge state; strong: strong ( $4 \mu\text{W}$ ) 594-nm orange laser for readout of charge state in real-time feedback; weak: weak ( $0.18 \mu\text{W}$ ) orange laser for single-shot readout of charge state. The NV electron spin ( $S = 1$ ), the attendant  $^{14}\text{N}$  nuclear spin ( $I = 1$ ), and one of randomly distributed  $^{13}\text{C}$  nuclear spins ( $I = 1/2$ ) constitute the interferometer. (B) Level diagrams of NV negative and neutral states denoted by  $\text{NV}^-$  and  $\text{NV}^0$  and the corresponding dynamics driven by the 532-nm green laser and the 594-nm orange laser. (C) Spin level structure of the ground state of  $\text{NV}^-$ -triplet. MW and RF pulses are used to coherently manipulate the NV electron spin and two nuclear spins ( $^{14}\text{N}$  and  $^{13}\text{C}$ ). (D) Projective measurement of the  $^{13}\text{C}$  nuclear spin. The dashed line denotes the threshold to determine which state it stays in. Credit: DOI: 10.1126/sciadv.abg9204

Many measurements are limited by standard quantum limit (SQL). SQL is defined as the measured noise levels set by quantum mechanics. Quantum entanglement can be used to beat SQL and approach an ultimate limit called Heisenberg limit (HL). Sub-SQL measurements have been realized in many systems under extreme conditions and sensors in these systems are not suitable for realistic measurements under ambient conditions.

Nitrogen-vacancy (NV) centers in diamond can be utilized as sensors for electron and nuclear magnetic resonance. They can work well in [environmental conditions](#) due to the protection of solid crystal lattice. An entire sub-SQL measurement process based on a single NV center includes initialization of NVs spins, entanglement under [ambient conditions](#), detection of physical quantities, and readout of results. Difficulties now emerged on initialization and entanglement of NV.

A research team led by Prof. Du Jiangfeng from University of Science and Technology of China (USTC) of the Chinese Academy of Sciences realized a sub-SQL measurement under ambient condition with NV

centers in diamond, and found that the use of entangled sensors can beat SQL and realize more accurate measurements. This study was published in *Science Advances*.

The researchers applied a real-time feedback technique to initialize spins to a highly pure state, and achieved the joint initialization of NV charge state, electron spin, and two nuclear spins with high fidelity.

They replaced squared pulse laser with chopped laser sequence for polarization of electron spin, improving the corresponding laser fidelity from 90% to 97.7%.

Additionally, the researchers optimized experiment setups to better control experimental conditions. Through sophisticated configuration for heat isolation and apropos proportion-integration-differentiation (PID) parameters for feedback, they realized a relatively low temperature fluctuation of 0.5mK during experiments and a highly stable magnetic field with the volatility of 1ppm.

This work opens up new perspectives for the investigation of solid-state spin systems, and lays the foundations for quantum sensing and computing.

**More information:** Tianyu Xie et al, Beating the standard quantum limit under ambient conditions with solid-state spins, *Science Advances* (2021). [DOI: 10.1126/sciadv.abg9204](https://doi.org/10.1126/sciadv.abg9204)

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