

# This quantum crystal could be a new dark matter sensor

August 5 2021

---

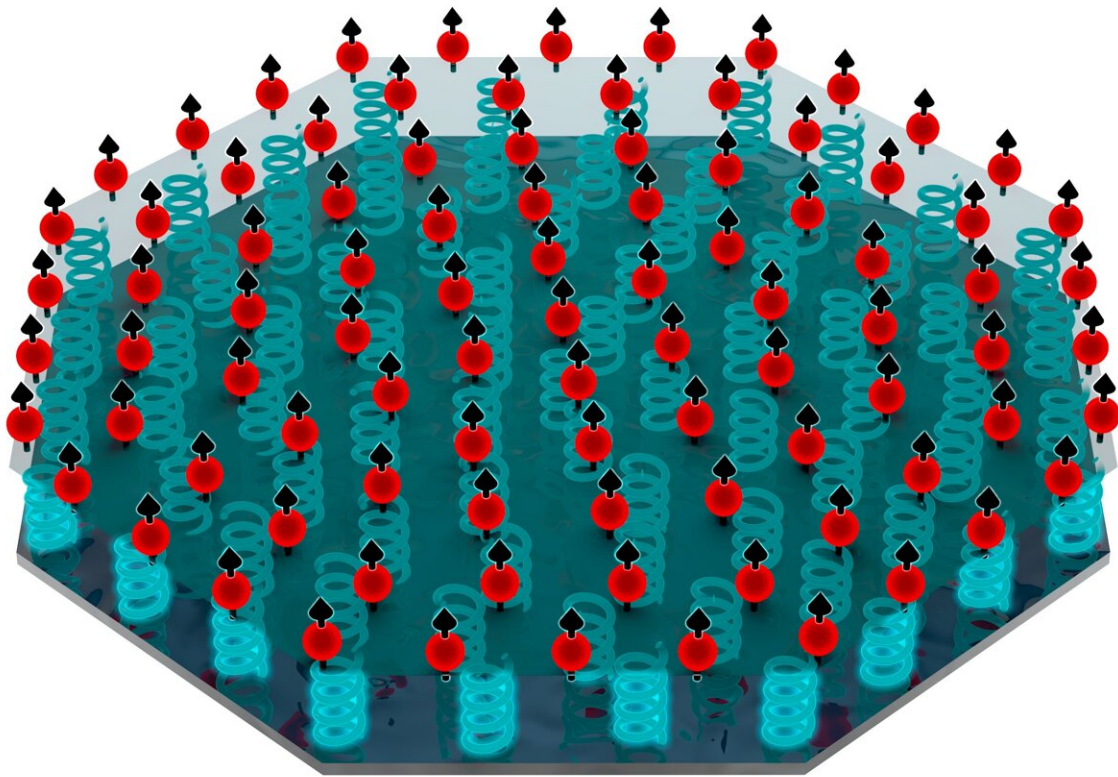


Illustration of NIST's quantum crystal. Credit: Burrows/JILA

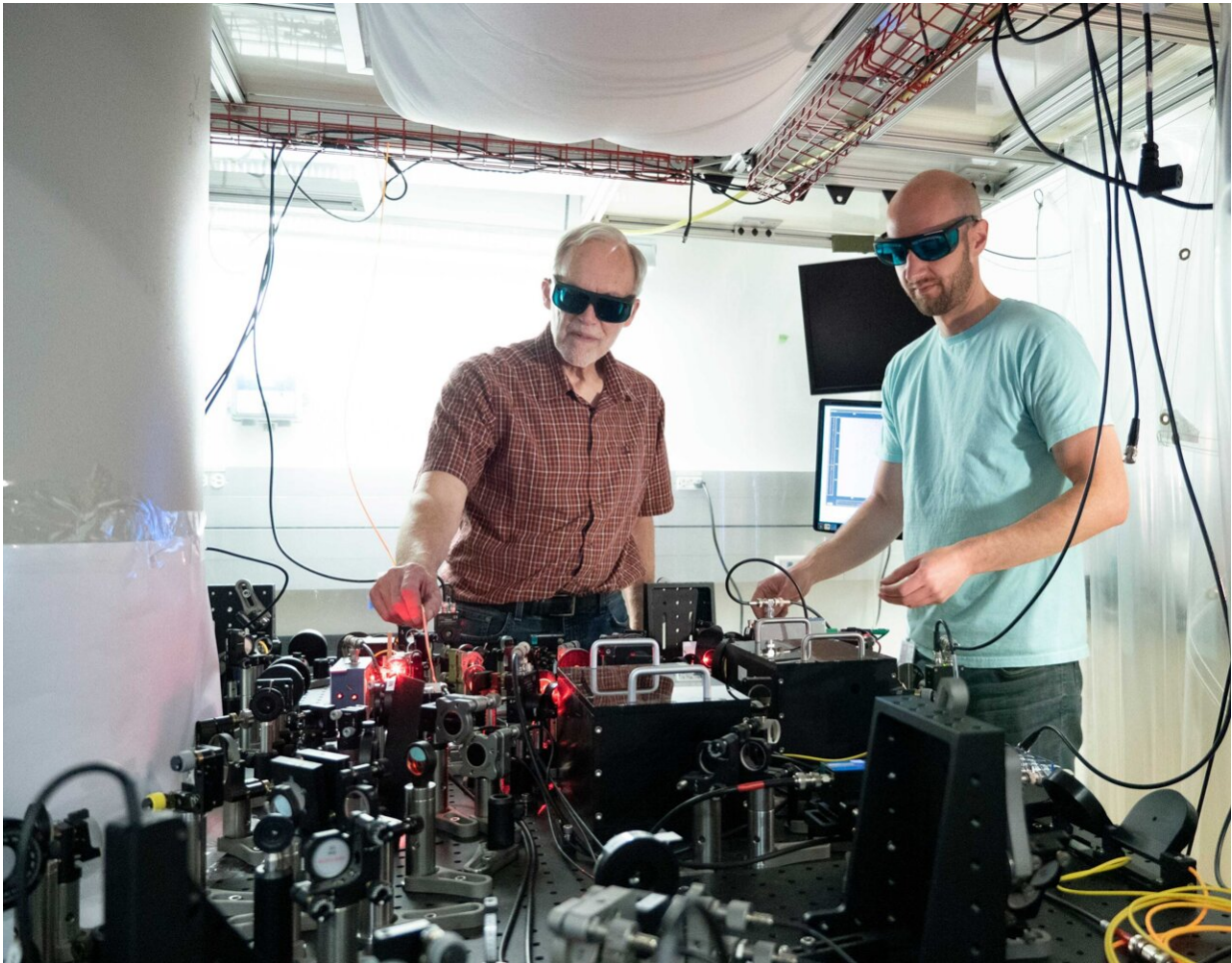
Physicists at the National Institute of Standards and Technology (NIST) have linked together, or "entangled," the mechanical motion and electronic properties of a tiny blue crystal, giving it a quantum edge in

measuring electric fields with record sensitivity that may enhance understanding of the universe.

The [quantum sensor](#) consists of 150 [beryllium ions](#) (electrically charged atoms) confined in a magnetic field, so they self-arrange into a flat 2D crystal just 200 millionths of a meter in diameter. Quantum sensors such as this have the potential to detect signals from [dark matter](#)—a mysterious substance that might turn out to be, among other theories, subatomic particles that interact with normal matter through a weak electromagnetic field. The presence of dark matter could cause the crystal to wiggle in telltale ways, revealed by collective changes among the crystal's ions in one of their electronic properties, known as spin.

As described in the Aug. 6 issue of *Science*, researchers can measure the vibrational excitation of the crystal—the flat plane moving up and down like the head of a drum—by monitoring changes in the collective spin. Measuring the spin indicates the extent of the vibrational excitation, referred to as displacement.

This sensor can measure external electric fields that have the same vibration frequency as the crystal with more than 10 times the sensitivity of any previously demonstrated atomic sensor. (Technically, the sensor can measure 240 nanovolts per meter in one second.) In the experiments, researchers apply a weak [electric field](#) to excite and test the crystal sensor. A dark matter search would look for such a signal.



NIST physicists John Bollinger (left) and Matt Affolter adjust the laser and optics array used to trap and probe beryllium ions in the large magnetic chamber (white pillar at left). The ion crystal may help detect mysterious dark matter. Credit: Jacobson/NIST

"Ion crystals could detect certain types of dark matter—examples are axions and hidden photons—that interact with normal matter through a weak electric field," NIST senior author John Bollinger said. "The dark matter forms a background signal with an oscillation frequency that depends on the mass of the dark matter particle. Experiments searching for this type of dark matter have been ongoing for more than a decade

with superconducting circuits. The motion of trapped ions provides sensitivity over a different range of frequencies."

Bollinger's group has been working with the ion crystal for more than a decade. What's new is the use of a specific type of laser light to entangle the collective motion and spins of a large number of ions, plus what the researchers call a "time reversal" strategy to detect the results.

The experiment benefited from a collaboration with NIST theorist Ana Maria Rey, who works at JILA, a joint institute of NIST and the University of Colorado Boulder. The theory work was critical for understanding the limits of the laboratory setup, offered a new model for understanding the experiment that is valid for large numbers of trapped ions, and demonstrated that the quantum advantage comes from entangling the spin and motion, Bollinger said.

Rey noted that entanglement is beneficial in canceling the ions' intrinsic quantum noise., However, measuring the entangled quantum state without destroying the information shared between spin and motion is difficult.

"To avoid this issue, John is able to reverse the dynamics and disentangle the spin and the motion after the displacement is applied," Rey said.

"This time reversal decouples the spin and the motion, and now the collective spin itself has the displacement information stored on it, and when we measure the spins we can determine the displacement very precisely. This is neat!"

The researchers used microwaves to produce desired values of the spins. Ions can be spin up (often envisioned as an arrow pointing up), spin down or other angles, including both at the same time, a special quantum state. In this experiment the ions all had the same spin—first spin up and then horizontal—so when excited they rotated together in a pattern

characteristic of spinning tops.

Crossed laser beams, with a difference in frequency that was nearly the same as the motion, were used to entangle the collective spin with the motion. The crystal was then vibrationally excited. The same lasers and microwaves were used to undo the entanglement. To determine how much the crystal moved, researchers measured the ions' spin level of fluorescence (spin up scatters light, spin down is dark).

In the future, increasing the number of ions to 100,000 by making 3D crystals is expected to improve the sensing capability thirtyfold. In addition, the stability of the crystal's excited motion might be improved, which would enhance the time reversal process and the precision of the results.

"If we are able to improve this aspect, this experiment can become a fundamental resource for detecting dark matter," Rey said. "We know 85% of the matter in the universe is made of dark matter, but to date we do not know what dark matter is made of. This experiment could allow us in the future to unveil this mystery."

Co-authors included researchers from the University of Oklahoma.

**More information:** K.A. Gilmore, M. Affolter, R.J. Lewis-Swan, D. Barberena, E. Jordan, A.M. Rey and J.J. Bollinger. Quantum-enhanced sensing of displacements and electric fields with two-dimensional trapped-ion crystals. *Science*. Aug. 5, 2021. [DOI: 10.1126/science.abi5226](https://doi.org/10.1126/science.abi5226)

Provided by National Institute of Standards and Technology

Citation: This quantum crystal could be a new dark matter sensor (2021, August 5) retrieved 20 March 2024 from <https://phys.org/news/2021-08-quantum-crystal-dark-sensor.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.