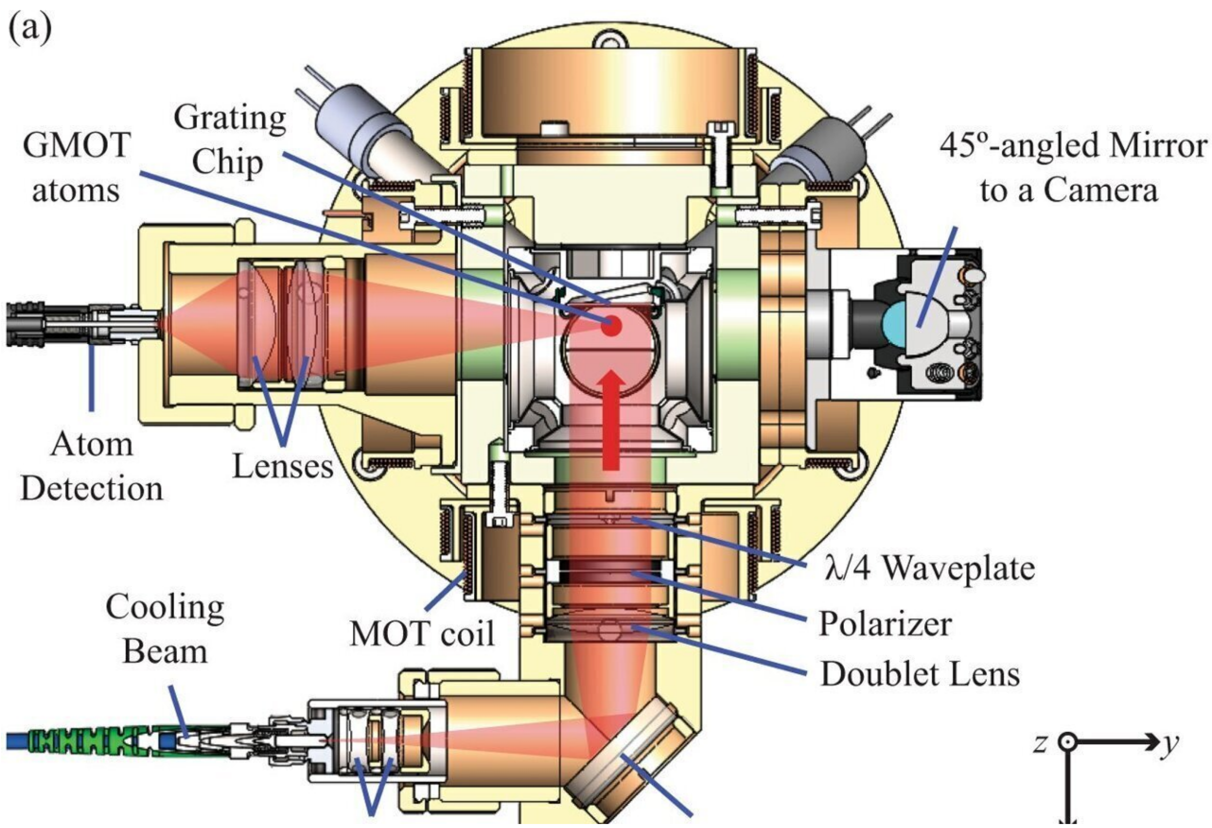
Navigating when GPS goes dark

October 21 2022, by Troy Rummler



Cross-sectional renderings of the LPAI sensor head. a, Horizontal cross-section showing the cooling-beam and atom-detection channels with fixed optical components. The cooling-channel light is delivered to the sensor head via a polarization maintaining (PM) fiber from which a large collimated Gaussian beam (D1/e2≈28mm) is used for cooling. The beam is truncated to ≈ 19 mm-diameter through the fused silica viewport in the compact LPAI sensor head. The light then passes through a polarizer and a λ/4 waveplate before illuminating the grating chip. The GMOT atoms (solid red circle) form ≈ 3.5 mm from the grating surface. The atom-detection channel was designed to measure atomic fluorescence through a multimode-fiber-coupled avalanche photodiode (APD) module. b, Vertical cross-section of the sensor head showing the designed beam paths for Doppler-sensitive Raman. Cross-linearly-polarized Raman beams are launched from the same PM fiber and the two components are split by a polarizing beam splitter (PBS). Fixed optics route the Raman beams to the GMOT atoms (solid red circle) with opposite directions. Credit: *Nature Communications* (2022). DOI: 10.1038/s41467-022-31410-4

Words like "tough" or "rugged" are rarely associated with a quantum inertial sensor. The remarkable scientific instrument can measure motion a thousand times more accurately than the devices that help navigate today's missiles, aircraft and drones. But its delicate, table-sized array of components that includes a complex laser and vacuum system has largely kept the technology grounded and confined to the controlled settings of a lab.

Jongmin Lee wants to change that.

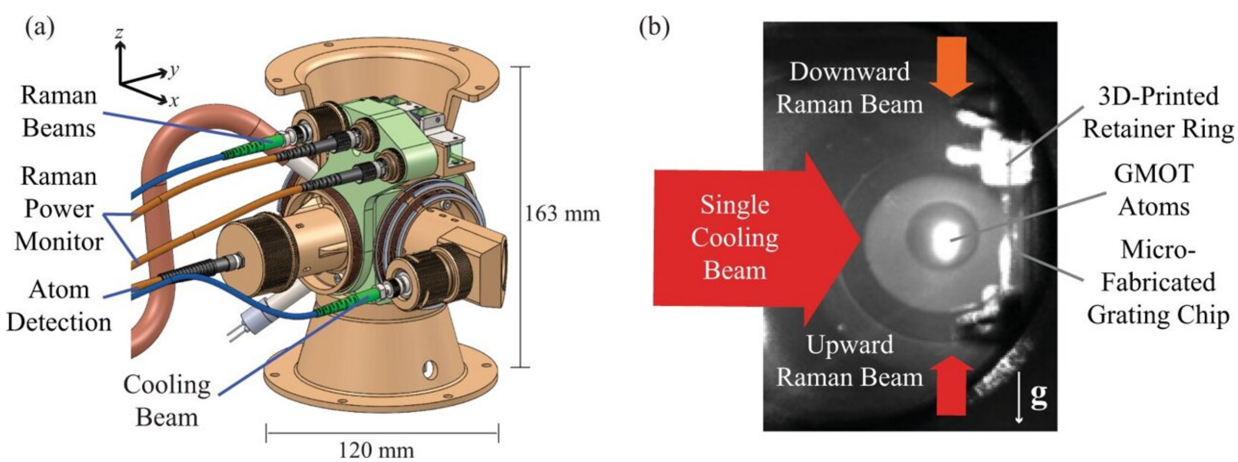
The atomic physicist is part of a team at Sandia that envisions quantum inertial sensors as revolutionary, onboard navigational aids. If the team can reengineer the sensor into a compact, rugged device, the technology could safely guide vehicles where GPS signals are jammed or lost.

In a major milestone toward realizing their vision, the team has successfully built a cold-atom interferometer, a core component of quantum sensors, designed to be much smaller and tougher than typical lab setups. The team describes their prototype in the academic journal *Nature Communications*, showing how to integrate several normally separated components into a single monolithic structure. In doing so, they reduced the key components of a system that existed on a large optical table down to a sturdy package roughly the size of a shoebox.

"Very high sensitivity has been demonstrated in the lab, but the practical matters are, for real-world application, that people need to shrink down the size, weight and power, and then overcome various issues in a dynamic environment," Jongmin said.

The paper also describes a roadmap for further miniaturizing the system using technologies under development.

The prototype, funded by Sandia's Laboratory Directed Research and Development program, demonstrates significant strides toward moving advanced navigation tech out of the lab and into vehicles on the ground, underground, in the air and even in space.



Concept of the compact light-pulse atom interferometer (LPAI) for high-dynamic conditions. **a** 3D rendering of the compact LPAI sensor head with fixed optical components and reliable optomechanical design. **b** Picture of the steady-state GMOT atoms in the sensor head.. Credit: *Nature Communications* (2022). DOI: 10.1038/s41467-022-31410-4

Ultrasensitive measurements drive navigational power

As a jet does a barrel roll through the sky, current onboard navigation tech can measure the aircraft's tilts and turns and accelerations to calculate its position without GPS, for a time. Small measurement errors gradually push a vehicle off course unless it periodically syncs with the satellites, Jongmin said.

Quantum sensing would operate in the same way, but the much better accuracy would mean onboard navigation wouldn't need to cross-check its calculations as often, reducing reliance on satellite systems.

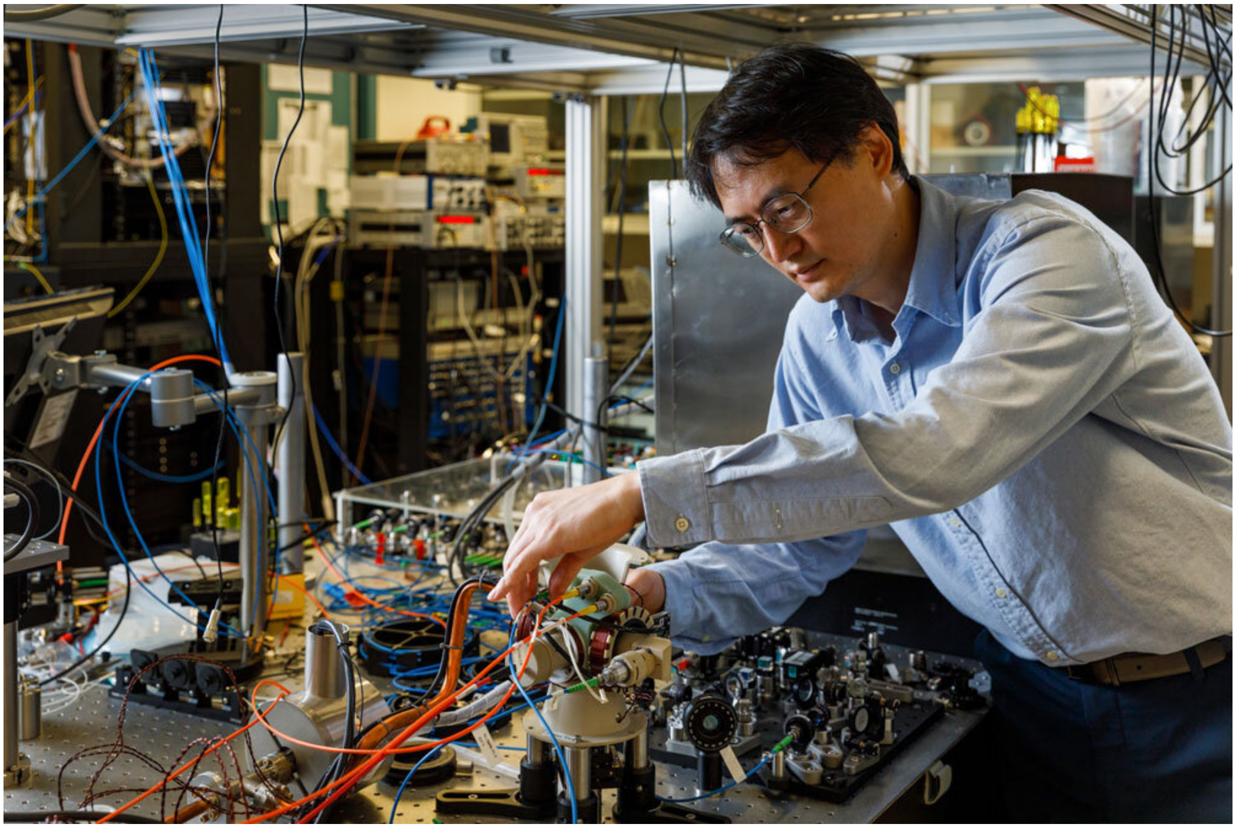
Roger Ding, a postdoctoral researcher who worked on the project, said, "In principle, there are no manufacturing variations and calibrations," compared to conventional sensors that can change over time and need to be recalibrated.

Aaron Ison, the lead engineer on the project, said to prepare the atom interferometer for a dynamic environment, he and his team used materials proven in extreme environments. Additionally, parts that are normally separate and freestanding were integrated together and fixed in place or were built with manual lockout mechanisms.

"A monolithic structure having as few bolted interfaces as possible was key to creating a more rugged atom interferometer structure," Aaron said.

Furthermore, the team used industry-standard calculations called finite element analysis to predict that any deformation of the system in conventional environments would fall within required allowances. Sandia has not conducted mechanical stress tests or field tests on the new design, so further research is needed to measure the device's strength.

"The overall small, compact design naturally leads towards a stiffer more robust structure," Aaron said.



Sandia atomic physicist Jongmin Lee examines the sensor head of a cold-atom interferometer that could help vehicles stay on course where GPS is unavailable. Credit: Bret Latter

Photonics light the way to a more miniaturized system

Most modern atom interferometry experiments use a system of lasers mounted to a large optical table for stability reasons, Roger said. Sandia's device is comparatively compact, but the team has already come up with further design improvements to make the quantum sensors much smaller using integrated photonic technologies.

"There are tens to hundreds of elements that can be placed on a chip smaller than a penny," said Peter Schwindt, the principal investigator on the project and an expert in quantum sensing.

Photonic devices, such as a laser or optical fiber, use light to perform useful work and integrated devices include many different elements. Photonics are used widely in telecommunications, and ongoing research is making them smaller and more versatile.

With further improvements, Peter thinks the space an interferometer needs could be as little as a few liters. His dream is to make one the size of a soda can.

In their paper, the Sandia team outlines a future design in which most of their laser setup is replaced by a single photonic integrated circuit, about eight millimeters on each side. Integrating the optical components into a circuit would not only make an atom interferometer smaller, it would also make it more rugged by fixing the components in place.

While the team can't do this yet, many of the photonic technologies they need are currently in development at Sandia.

"This is a viable path to highly miniaturized systems," Roger said.

Meanwhile, Jongmin said integrated photonic circuits would likely lower costs and improve scalability for future manufacturing.

"Sandia has shown an ambitious vision for the future of quantum sensing in navigation," Jongmin said.

More information: Jongmin Lee et al, A compact cold-atom interferometer with a high data-rate grating magneto-optical trap and a photonic-integrated-circuit-compatible laser system, *Nature Communications* (2022). DOI: 10.1038/s41467-022-31410-4

Provided by Sandia National Laboratories

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