LIGHT+ MATTER

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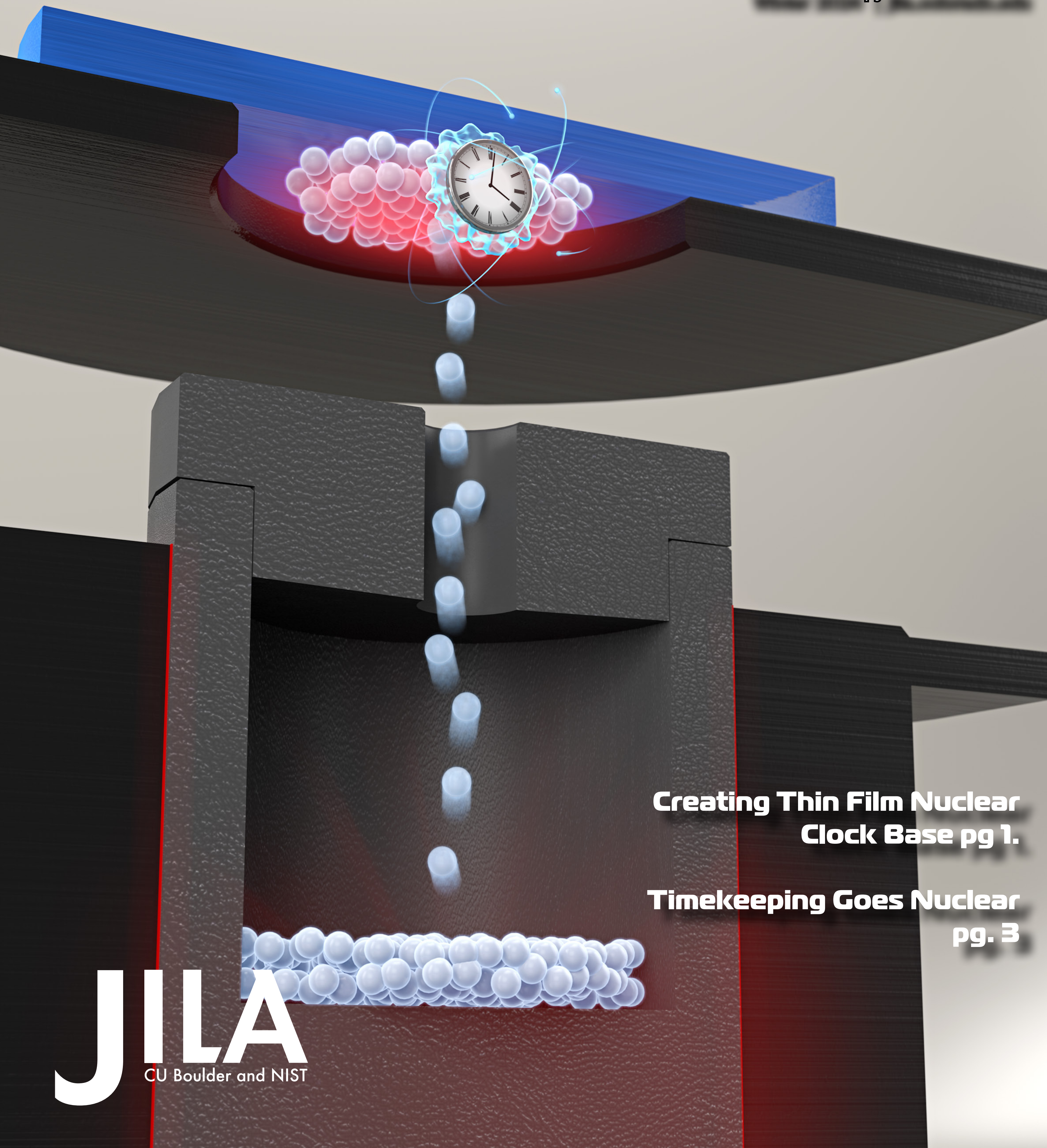

Creating Thin Film Nuclear Clock Base pg 1.

Timekeeping Goes Nuclear pg. 3

JILA
CU Boulder and NIST

JILA staff member James Fung-A-Fat gives a five-minute talk on American Sign Language (ASL) as part of the 2024 JILA-X talks, a community event held every October.
Credit: Austen Hughes/JILA

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Research Articles

Feature Articles

Building a Safer and More Affordable Nuclear Clock

In the quest for ultra-precise timekeeping, scientists have turned to nuclear clocks. Unlike optical atomic clocks—which rely on electronic transitions—nuclear clocks utilize the energy transitions in the atom's nucleus, which are less affected by outside forces, meaning this type of clock could potentially keep time more accurately than any previously existing technology.

However, building such a clock has posed major challenges—thorium-229, one of the isotopes used in nuclear clocks, is rare, radioactive, and extremely costly to acquire in the substantial quantities required for this purpose.

Reported recently in a new study published in *Nature,* a team of researchers, led by JILA and NIST Fellow and University of Colorado Boulder physics professor Jun Ye, in collaboration with Professor Eric Hudson's team at UCLA's Department of Physics and Astronomy, have found a way to make nuclear clocks a thousand times less radioactive and more cost-effective, thanks to a method creating thin films of thorium tetrafluoride (ThF_4).

The successful use of thin films marks a potential turning point in the development of nuclear clocks. Using thin-film technology in nuclear clocks is commensurate with semiconductors and photonic integrated circuits, suggesting that future nuclear clocks could be more accessible and scalable.

"A key advantage of nuclear clocks is their portability, and to fully unleash such an attractive potential, we need to make the systems more compact, less expensive, and more radiation-friendly to users," said Ye.

JILA has been at the forefront of atomic and optical clock research for decades, with Ye's laboratory making contributions advancing new standards in precision timekeeping. Physicists have been trying to observe the energy transition of thorium-229 for nearly 50 years. In September 2024, researchers in Ye's laboratory reported the first high-resolution spectrum of the nuclear transition and determined the absolute frequency based on the JILA Sr optical lattice clock. Their result was published as a cover article in *Nature.*

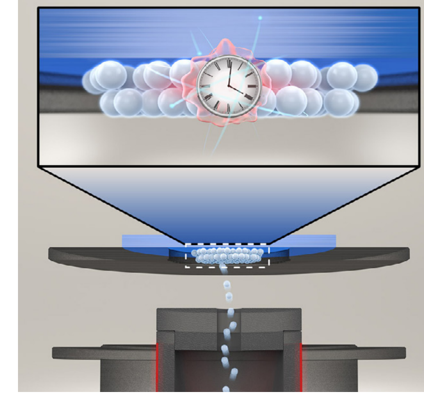
To build their nuclear clock setup, the team worked with radioactive thorium-229 crystals, collaborating with researchers at the University of Vienna.

"The growth of that crystal is an art in itself, and our collaborators in Vienna spent many years of effort to grow a nice single crystal for this measurement," explains Chuankun Zhang, a graduate student at JILA and first author of both *Nature* studies.

Previous approaches using thorium-doped crystals required more radioactive material. As thorium-229 is often sourced from uranium via nuclear decay, this leads to additional radiation safety and cost considerations.

The researchers collaborated closely with CU Boulder's Environmental Health & Safety department to safely build and study their nuclear clock. As the team worked to observe the nuclear transitions in thorium-doped crystals, they simultaneously pursued methods to make the clock safer and more cost-effective by developing thin film coatings to reduce the amount of radioactive thorium needed.

To produce the thin films, the researchers used a process called physical vapor deposition (PVD), which involved heating thorium fluoride in a chamber until it vaporized. The vaporized atoms then condensed on a substrate, forming a thin, even layer of thorium fluoride about 100 nanometers thick. The researchers selected sapphire and magnesium fluoride as



A diagram showing the physical vapor deposition (PVD) process using thorium-fluoride.
Credit: Steven Burrows/Ye Group

substrates because of their transparency to the ultraviolet light used to excite the nuclear transition.

"If we have a substrate very close by, the vaporized thorium fluoride molecules touch the substrate and stick to it, so you get a nice, even thin film," Zhang says.

This method used just micrograms of thorium-229, making the product a thousand times less radioactive while producing a dense layer of active thorium nuclei. Working with the JILA Keck Metrology laboratory and JILA instrument maker Kim Hagen, the researchers reliably reproduced films that could be tested for potential nuclear transitions using a laser.

However, the team faced a new challenge. Unlike in a crystal, where every thorium atom was situated in an ordered environment, the thin films produced variations in thorium environments, shifting their energy transitions and making them less consistent.

JILA graduate student Jack Doyle, who was also involved in this study, elaborates, "Wolfgang Pauli was rumored to have said that 'God invented the bulk and the surface is of the devil,' but he might as well have said this because the number of factors that are hard to learn about for a particular surface is immense."

After preparing the films, JILA researchers sent them to Professor Eric Hudson at UCLA, who used a high-power laser with a much greater spectral width to test the nuclear transitions. This broad-spectrum laser has all of its optical power concentrated in one spectral location instead of a frequency comb that has regularly spaced spectral lines over a larger spectral distance. This allowed the UCLA team to excite the thorium nuclei effectively, even though the observed linewidth is broader than previously seen in the previous study. When the laser's energy precisely matched the energy required for the transition, the nuclei emitted photons as they relaxed back to their original state. By detecting these emitted photons, the researchers could confirm successful nuclear excitations, verifying the thin film's potential to serve as a frequency reference for nuclear clocks.

"We made the thin film, we characterized it, and it looked pretty good," explains JILA graduate student Tian Ooi, who was also involved in this research. "It was cool to see that the nuclear decay signal was actually there."

Based on their findings, the researchers are excited about potential future applications.

"The general advantage of using clocks in a solid state, as opposed to in a trapped-ion setting, is that the number of atoms is much, much larger," Higgins elaborates. "There are orders and orders of magnitude more atoms than one could feasibly have in an ion trap, which helps with your clock stability."

These thin films could additionally allow nuclear timekeeping to move beyond laboratory settings by making them compact and portable.

"Imagine something you can wear on your wrist," Ooi says. "You can imagine being able to miniaturize everything to that level in the far, far future."

While this level of portability is still a distant goal, it could revolutionize sectors that rely on precise timekeeping, from telecommunications to navigation.

Chuankun Zhang, Lars von der Wense, Jack F. Doyle, Jacob S. Higgins, Tian Ooi, Hans U. Friebel, Jun Ye, R. Elwell, J. E. S. Terhune, H. W. T. Morgan, A. N. Alexandrova, H. B. Tran Tan, Andrei Derevianko, and Eric R. Hudson. "$^{229}ThF_4$ thin films for solid-state nuclear clocks." Nature, 636(8043), 603–608 (2024).

Written by Kenna Hughes-Castleberry

To Measure or Not to Measure, but Dynamically Evolve—That is the Question

One way to get around the fundamental quantum fuzziness in precision measurement is to entangle the atoms, or make them talk, so that one cannot independently describe their quantum states. In this case, it is possible to create a situation where the quantum noise of one atom in a sensor can be partially canceled by the quantum noise of another atom such that the total noise is quieter than one would expect for independent atoms. This type of entangled state is called a “squeezed state." Squeezing is related to the Heisenberg Uncertainty Principle, which limits how accurately a researcher can measure two related properties simultaneously—such as the momentum and position of a particle—where the researchers can know more about one parameter than the other. Squeezing overcomes this limitation by making one of these variables more uncertain, or less known, allowing a more accurate measurement of one of the variables.

Up to now, there have been two leading ways to generate squeezed states, using atoms that interact with light. One way, unitary evolution, is by transforming an initially uncorrelated (not entangled) state into a spin-squeezed state via dynamical evolution via a specific type of unitary interaction. One can imagine the initially uncorrelated state as a round piece of dough where your hand slowly squeezes the dough in one direction while making the other direction wider. The other way is to perform quantum nondemolition measurements (QND) that allow one to pre-measure the quantum noise and subtract it from the final measurement outcome. The QND approach has currently realized the largest amounts of observed squeezing between the two methods, but it is not clear which protocol is actually optimal, given fundamental experimental constraints, or even if it would be better to use both protocols at the same time.

This is why JILA and NIST Fellows and University of Colorado Boulder physics professors Ana Maria Rey and James K. Thompson and their teams wanted to create a guide on which protocol is best to use under fundamental and realistic experimental conditions. Their results, published in *Physical Review Research,* revealed that when measurement efficiency is greater than 19%, the QND measurement protocol outperformed unitary dynamical evolution.

First author and former JILA graduate student Diego Barberena, now a postdoc at the University of Cambridge, explains, “I think that it's beneficial to have all the results together in a single place because they are scattered all over the literature and written in ways that may be easier to parse for some physicists but not others, given the technical language of each different experiment. So, we’re happy to give people a paper where all protocols are in one place.”

Within quantum research, unitary evolution and QND are two of the most commonly used methods to create spin-squeezing in atoms. Both revolve around an ensemble of atoms placed in an optical cavity. By measuring the light leaking out of the cavity in QND experiments, the researchers can determine if the atoms are in a spin-squeezed state or not.

In the unitary evolution method, atoms interact by exchanging photons inside the optical cavity while swapping their internal levels or spins, a process that allows them to evolve in a controlled, predictable way which shapes their noise distribution in a specific desirable way: from a circle to an ellipse. This process is governed by a well-defined set of rules that describe the system's evolution, and no external measurements are involved, meaning the researchers didn’t observe or measure the light leakage during the experiment.

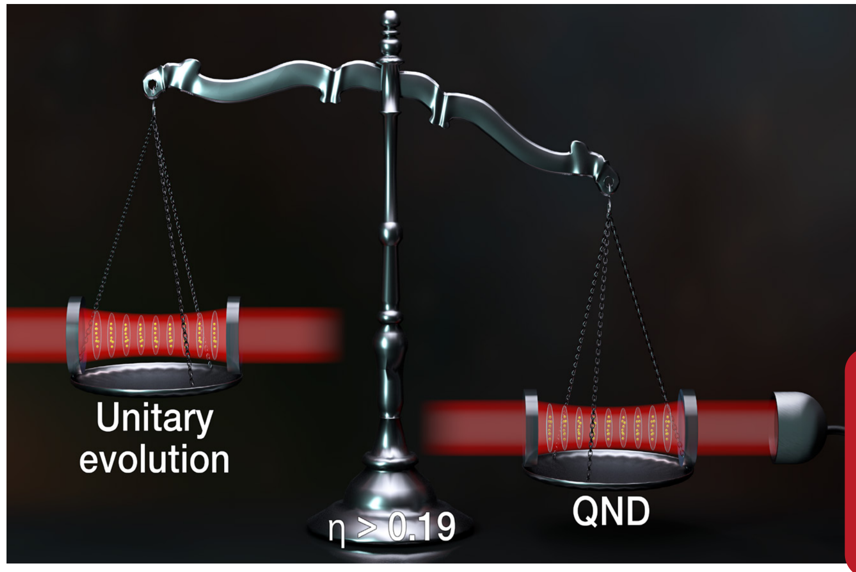
In contrast, QND uses a different method to measure quantum dynamics.

Thompson elaborates, “QND measurements are very special. They involve measuring the light that leaks from the optical cavity to gather information about how many atoms are in which quantum state without knowing which atoms are in which quantum state.”

To compare the two methods, researchers developed a detailed simulation that modeled how atoms interact with a shared light field inside an optical cavity. In this simulation, they accounted for real-world factors such as quantum noise, imperfect optical cavities, decoherence, and a crucial parameter known as quantum efficiency.

Quantum efficiency refers to the fraction of all the information that is accessible to the experimentalist.

“Quantum efficiency is basically a quantity describing how well you can measure a system,” adds former JILA graduate student Anjun Chu, second author and now a postdoctoral fellow at the University of Chicago. “It revolves around the percentage of light leakage that can be measured out of the cavity. The efficiency is one, if you can perfectly detect all photons coming out of the cavity. In this case, it would be better to turn off unitary evolution and focus only on QND. If the efficiency is zero, you’re measuring no light, so you get no information from a measurement. In this case, it would be better to suppress the light leakage and let the system evolve near unitary. Between zero and one, there is a combination of measurement and unitary evolution. We are trying to determine which of the two methods or their combination would win.”



When the detection efficiency of the quantum nondemolition (QND) measurement is above 0.19, QND outperforms unitary evolution for the preparation of spin squeezing in a QED cavity. Credit: Steven Burrows/Rey and Thompson groups

The simulation tested different levels of quantum efficiency to see how both methods performed under various conditions. The results showed that when quantum efficiency was above 19%, the QND method outperformed unitary evolution in generating spin-squeezed states. This was because the high efficiency allowed the QND process to gather enough information from the system to reduce uncertainty and improve precision. Below that threshold, unitary evolution was more effective.

Thompson notes, “In previous experimental work, we achieved net quantum efficiencies above 30%, and it is just a matter of technology development to achieve greater than 90%. However, in quantum sensing, one often juggles many competing requirements that might make unitary evolution more advantageous. Now we know when to switch between one approach versus the other.”

The researchers also found that the combination of QND and unitary evolution did not provide the distinct advantage they expected, suggesting that one or the other method should be favored instead.

Diego Barberena, Anjun Chu , James K. Thompson , and Ana Maria Rey. "Trade-offs between unitary and measurement induced spin squeezing in cavity QED." Physical Review Research, 6(3), L032037, 2024.

Written by Kenna Hughes-Castleberry

New Quantum Timekeeper Packs Several Clocks into One

Imagine walking into a room where several different grandfather clocks hang on the walls, each ticking at a different pace.

Quantum physicists at CU Boulder and the National Institute of Standards and Technology (NIST) have essentially recreated that room at the scale of atoms and electrons. The team's advancement could pave the way for new kinds of optical atomic clocks, devices that track the passage of time by measuring the natural "ticking" of atoms.

The group's new clock is made from a few dozen strontium atoms trapped in a lattice pattern. To improve the device's performance, the team generated a type of ghostly interaction, known as quantum entanglement, between groups of those atoms—basically squishing four different kinds of clocks into the same time-keeping apparatus.

It's not your ordinary pocket watch: The researchers showed that, at least under a narrow range of conditions, their clock could beat a benchmark for precision called the "standard quantum limit"—what physicist Adam Kaufman refers to as the "Holy Grail" for optical atomic clocks.

"What we're able to do is divide the same length of time into smaller and smaller units," said Kaufman, senior author of the new study and a fellow at JILA, a joint research institute between CU Boulder and NIST. "That acceleration could allow us to track time more precisely. "The team's advancements could lead to new quantum technologies. They include sensors that can measure subtle changes in the environment, such as how Earth's gravity shifts with elevation.

Kaufman and his colleagues, including first author Alec Cao, a graduate student at JILA, published their findings in the journal *Nature.*

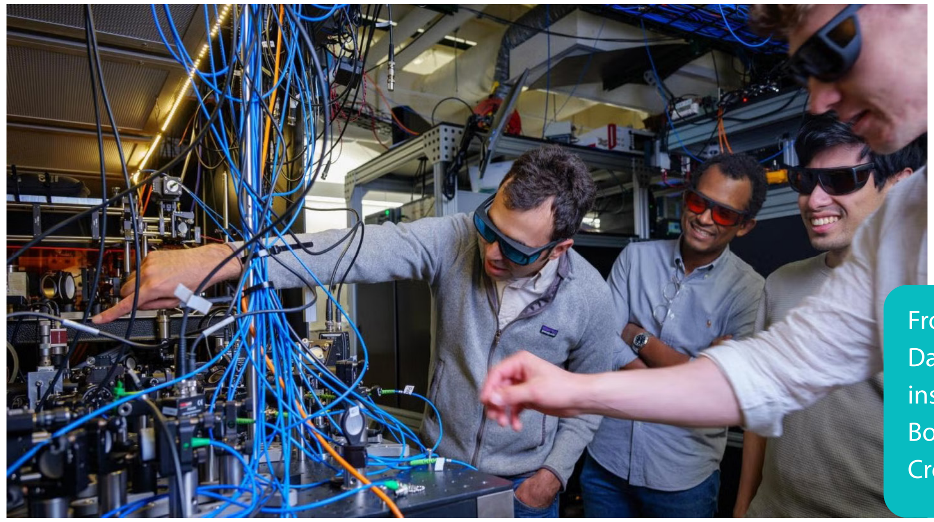
Lassoing Atoms

The research represents another major advancement for optical atomic clocks, which can do a lot more than tell time.

To make such a device, scientists typically begin by trapping and chilling a cloud of atoms down to frigid temperatures. They then zap those atoms with a powerful laser. If the laser is tuned just right, electrons orbiting those atoms will jump from a lower energy level to a higher energy level, then back again. Think of it like the pendulum of a grandfather clock swinging back and forth—only these clocks tick more than a trillion times per second.

They're extremely precise. The newest optical atomic clocks at JILA, for example, can detect the change in gravity if you lift them up by just a fraction of a millimeter.

"Optical clocks have become an important platform in many areas of quantum physics because they allow you to control individual atoms to such a high degree—both where those atoms are, and also what states they're in," Kaufman said.



From left to right, Adam Kaufman, Nelson Darkwah Oppong, Alec Cao and Theo Lukin Yelin inspect an optical atomic clock at JILA on the CU Boulder campus.
Credit: Patrick Campbell/CU Boulder

But they also have a big drawback: In quantum physics, things as small as atoms never behave exactly like you'd expect. These natural uncertainties set what seems to be an unbreakable limit on just how precise a clock can get.

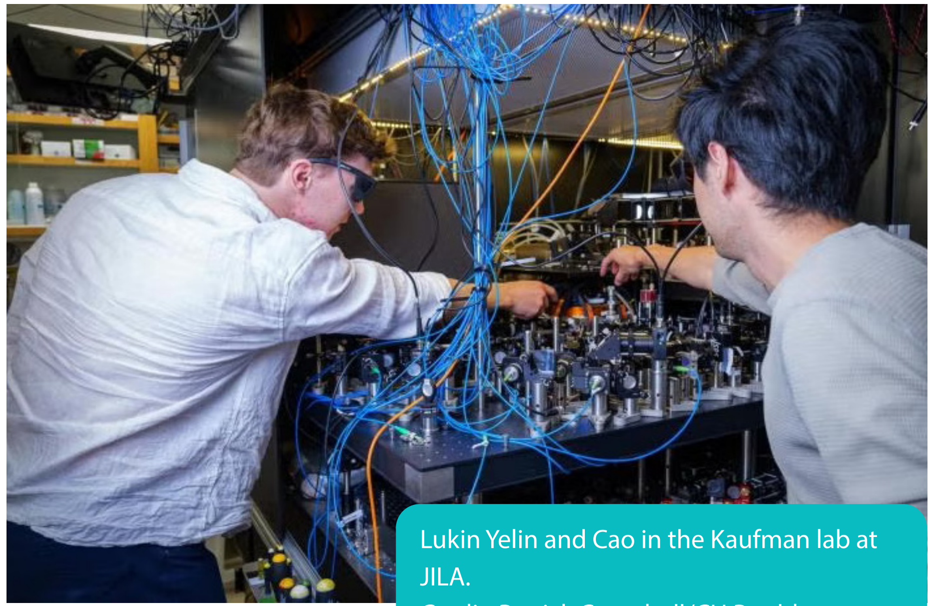
Entanglement, however, could provide a workaround.

Fluffy Orbits

Kaufman explained that when two particles become entangled, information about one of them will automatically reveal information about the other. In practice, entangled atoms in a clock behave less like individuals and more like a single atom, which makes their behavior easier to predict.

In the current study, the researchers generated this kind of quantum link by nudging their strontium atoms so that their electrons orbited far away from their nuclei—almost as if they were made of cotton candy.

"It's like a fluffy orbit," Kaufman said. "This fluffiness means that if you bring two atoms close enough, the electrons can feel each other nearby, resulting in a strong interaction between them."



Lukin Yelin and Cao in the Kaufman lab at JILA.
Credit: Patrick Campbell/CU Boulder

Those conjoined pairs also tick at a faster pace than atoms on their own.

The team experimented with creating clocks that included a combination of individual atoms and entangled groups of two, four and eight atoms—in other words, four clocks ticking at four rates in one.

They found that, at least under certain conditions, entangled atoms have a lot less uncertainty in their ticking than the atoms in a traditional optical atomic clock.

"That means that it takes us less time to get to the same level of precision," he said.

Exquisite Control

He and his colleagues still have a lot of work to do. For a start, the researchers can only run their clock effectively for about 3 milliseconds. Longer than that, and the entanglement between atoms starts to slip, causing the atomic ticking to become chaotic.

But Kaufman sees a lot of potential for the device. His team's approach toward entangling atoms could, for example, form the basis for what physicists call "multi-qubit gates"—the basic operations that perform calculations in quantum computers, or devices that could one day outperform traditional computers at certain tasks.

"The question is: Can we create new kinds of clocks with tailored properties, enabled by the exquisite control that we have in these systems?" Kaufman said.

Alec Cao, William J. Eckner, Theodor Lukin Yelin, Aaron W. Young, Sven Jandura, Lingfeng Yan, Kyungtae Kim, Guido Pupillo, Jun Ye, Nelson Darkwah Oppong, and Adam M. Kaufman. "Multi-qubit gates and Schrödinger cat states in an optical clock." Nature, 634(8033), 315–320, 2024.

Written by Dan Strain, guest contributor

Creating a Global Map of Different Physics Laboratory Classes

Physics lab courses are vital to science education, providing hands-on experience and technical skills that lectures can't offer. Yet, it's challenging for those in Physics Education Research (PER) to compare course to course, especially since these courses vary wildly worldwide. To better understand these differences, JILA Fellow and University of Colorado Boulder physics professor Heather Lewandowski and a group of international collaborators are working towards creating a global taxonomy, a classification system that could create a more equitable way to compare these courses. Their findings were recently published in *Physical Review Physics Education Research.*

With a global taxonomy, instructors can have a more precise roadmap for navigating and improving their courses, leading to a brighter future for physics education worldwide.

"The ultimate taxonomy will help education researchers both understand physics lab education broadly and also be able to compare and contrast studies done around the world," says Lewandowski.

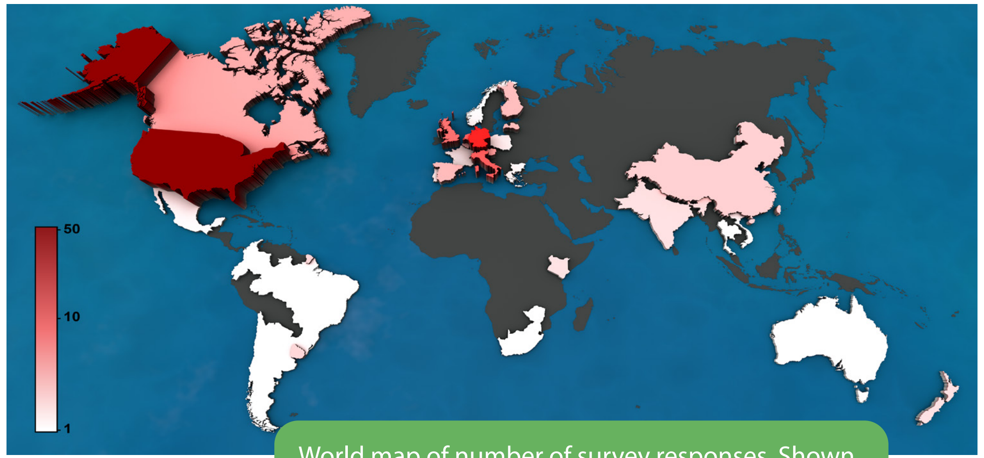
According to Gayle Geschwind, the paper's first author and a recently graduated JILA Ph.D. researcher, the project began as an international conversation between physicists who realized that comparing lab course assessments was not always straightforward.

"It can be hard for instructors to get useful information," said Geschwind. "For example, a sophomore-level course can't easily be compared to an introductory one, but right now, that's often the only data available for comparison. Lab courses vary in how they're taught, the methods they use, and the equipment the students can interact with. And these lab courses are expensive; some use nice equipment, others aren't able to."

This mismatch prompted the researchers to develop a method that will eventually result in a database of the many different laboratory courses for physics across the globe. The team's first task was to build a robust survey to capture how lab courses are structured worldwide.

Once the survey was ready, the team interviewed instructors from 23 countries to ensure the questions were clear and applicable to different educational systems. From these early interviews, Geschwind, Lewandowski, and their collaborators improved their survey. While the earlier editions had options for instructors to put in the major and minor goals of the course, based on the feedback from the interviews, the team decided to add an option for a future goal, where an instructor could add other techniques students could learn in the future.

Along with the improvements to their survey, Lewandowski and Geschwind found a challenge early on in the phrasing of some of the survey questions.



World map of number of survey responses. Shown on a log scale, each colored country has at least one response; countries in gray have no responses. Credit: Steven Burrows/Lewandowski group

Geschwind shared a telling anecdote: "Heather and I spent three or four hours on one question's wording about how many students are in each lab section...It turns out 'lab section' doesn't mean the same thing outside the U.S., and eventually, we had to phrase the question very creatively to get our point across."

Beyond the language issues, the team discovered surprising differences in lab structures. In some countries, labs might meet daily for two weeks rather than weekly throughout the semester. Other differences were more extreme, like an interviewee based in Africa who shared that students sometimes had to "stick screwdrivers into electrical outlets" just to see if the power was on that day—a stark contrast to the well-equipped labs in wealthier nations.

Finding the General Themes

After finalizing the survey through an iterative process of interviews and revisions, the team sent it to their network of lab instructors, asking them to complete it and share it with others. While the researchers initially gathered responses primarily from Western Europe and the U.S., they soon expanded their efforts by compiling a list of every country and cold-mailing institutions worldwide. To their surprise, they received many responses, including from regions historically underrepresented in STEM, helping enrich the global database of physics lab courses.

From the survey responses, the researchers found some prominent initial themes. Across the board, lab courses emphasized technical skills and group work. Geschwind was fascinated by the fact that "an introductory mechanics lab course doesn't differ much from place to place" despite the variety in equipment and resources.

Another interesting result was about the number of learning goals instructors have for their students in the courses. On average, instructors identified nearly 12 distinct goals per course, highlighting the complex nature of laboratory environments as part of courses designed to foster a broad range of knowledge and skill development.

Perhaps one of the survey's most unexpected outcomes was its immediate impact on the instructors who took it. Many began rethinking their own courses during the process. In fact, the survey even included links to resources and best practices that participants could explore, making it a research tool and a learning opportunity for the instructors.

Looking ahead, the research team has big plans for their data. The ultimate goal is to create a global database of lab courses (and standardized categorization of these courses) that can help instructors compare and improve their teaching methods.

"We eventually want to get this database of information...so if an instructor wants to restructure their electronics course, they can see what others are doing," she added.

The project is currently unfunded, with most of the team volunteering their time, but that hasn't stopped them from envisioning future developments. Geschwind suggested that in the future, the team could use clustering algorithms to group similar courses and identify trends, such as whether certain types of lab courses, e.g., second-year electronics labs, unexpectedly share similarities with others, such as senior-level quantum labs. As the project progresses, the team hopes to gather more data, particularly from underrepresented regions, to make the taxonomy even more comprehensive.

"Eventually, this could lead to better assessments and more informed teaching practices, making physics lab education stronger globally," Geschwind said. said.

Gayle Geschwind, Micol Alemani, Michael F.J. Fox, P.S.W.M. Logman, Eugenio Tufino and H.J. Lewandowski. " Development of a global landscape of undergraduate physics laboratory courses." Physical Review Physics Education Research, 20(2), 020117 2024.

Written by Kenna Hughes-Castleberry,

No Cavity, No Party: Free-Space Atoms Give Superradiant Transition a

Isolated atoms in free space radiate energy at their own individual pace. However, atoms in an optical cavity interact with the photons bouncing back and forth from the cavity mirrors, and by doing so, they coordinate their photon emission and radiate collectively, all in sync. This enhanced light emission before all the atoms reach the ground state is known as superradiance. Interestingly, if an external laser is used to excite the atoms inside the cavity moderately, the absorption of light by the atoms and the collective emission can balance each other, letting the atoms relax to a steady state with finite excitations.

However, above a certain laser energy level, the nature of the steady state drastically changes since atoms inside the cavity cannot collectively emit light fast enough to balance the incoming light. As a result, the atoms keep emitting and absorbing photons without reaching a stable, steady state. While this change in steady-state behaviors was theoretically predicted decades ago, it hasn't yet been observed experimentally.

Recent research at the Laboratoire Charles Fabry and the Institut d'Optique in Paris studied a collection of atoms in free space forming an elongated, pencil-shaped cloud and reported the potential observation of this desired phase transition. Yet, the results of this study puzzled other experimentalists since atoms in free space don't easily synchronize.

To better understand these findings, JILA and NIST Fellow Ana Maria Rey and her theory team collaborated with an international team of experimentalists. The theorists found that atoms in free space can only partially synchronize their emission, suggesting that the free-space experiment did not observe the superradiant phase transition. These results are published in *PRX Quantum.*

"While our current simulations were able to reproduce the experimental data, and explained why full synchronization cannot take place under current experimental conditions, a remaining open question is whether the phase transition could happen under different conditions and at higher densities, where our theoretical methods fail and instead a genuine quantum description is required," explains Rey.

From Experiment to Theory

In physics, solving complex problems often requires the combined efforts of both theorists and experimentalists. Theorists develop mathematical models and simulations to predict how systems should behave. Conversely, experimentalists conduct experiments to test and challenge these predictions. This collaboration helps bridge the gap between abstract ideas and observable phenomena.

"One of the big questions people are trying to answer is if it's possible to create entangled states in different atomic systems," explains Sanaa Agarwal, a graduate student in Rey's group and the paper's first author. "In a cavity system, this is enabled by these collective all-to-all interactions [atoms interacting one-to-one], but in free space, that still needs to be clarified."

A cavity system can be fine-tuned to drive atoms into specific quantum states. In contrast, free-space systems are less controlled.

"In free space, there are many effects to look at, like interaction-induced frequency," says Agarwal. "You also have emission into all possible directions, not just predominantly into the cavity [mode] system. So, these effects are expected to change the physics in the system, and that's why we started looking into it, and indeed, we found it's quite different."

The specific free-space experimental conditions raised the question of whether the observed behaviors were truly superradiant or coincidental.

To answer these questions, the researchers carried out a series of theoretical simulations using a model that accounted for each atom as a dipole, absorbing and emitting photons from the laser and the light emitted by the other atoms.

"This was an interesting challenge, as the number of accessible states increases linearly in the cavity, but in free space, it can increase exponentially with system size," Rey elaborates. "In many cases, the interactions can be weak enough that simplified treatments are possible, but it was initially not clear if that was going to be the case in this experiment."

Argawal adds, "We considered a microscopic model, in which every atom acts like a dipole, and used it to study the emergent properties of the entire atomic cloud. The laser beam is a plane wave, imprinting a specific phase pattern on the atoms, which is crucial in determining how the atoms interact."

The researchers simulated different conditions, including varying laser power and atom density, to see how these factors influenced the system's behavior.

"Our simulations showed that a "mean-field approximation", which reduces the complexity greatly by treating the atoms as classical magnets, was enough to reproduce the physics," Rey notes.

This model was validated with more complex approaches to ensure consistent results.

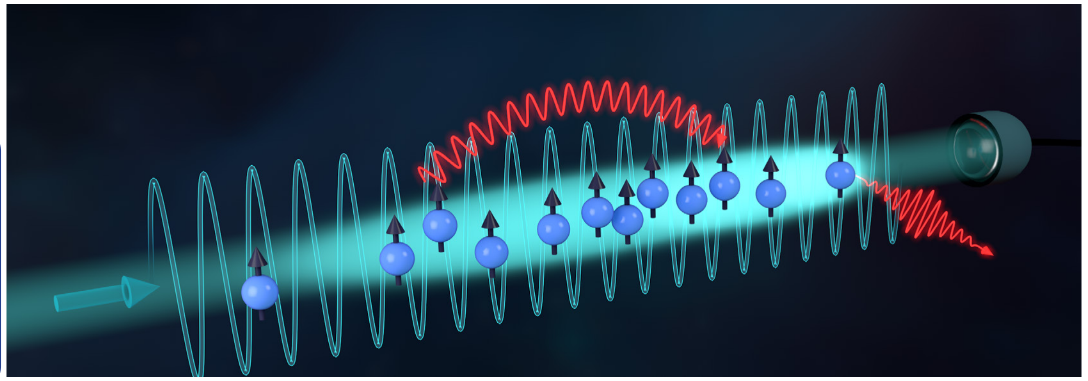
When Theory and Experiment Agree

"When we were comparing the theory with the data, we were unsure if it would agree," Agarwal says. "Some of the data was fairly easy to compare because there was less ambiguity in the experimental apparatus. So, when our findings agreed with those results, it gave us a vote of confidence that what we're doing makes sense."

From their simulations, the researchers concluded that while the free-space experiment agreed with the cavity model, within a narrow range of laser intensities and atom densities, the two systems generally behaved very differently. As the laser power increased beyond a certain threshold, the collective effects that gave rise to superradiance in the cavity disappeared into free space, and the atoms acted more like independent emitters rather than a coordinated group. These findings open new research avenues in quantum physics and validate the great value of experiment-theory collaborations to gain a better understanding of the underlying physics.

These findings open new research avenues in quantum physics and validate the great value of experiment-theory collaborations to gain a better understanding of the underlying physics.

Rey adds, "Our group will be looking for ways to improve our calculations and to prepare us for the new exciting measurements coming ahead."



A pencil-shaped ultracold gas of frozen two-level atoms interacting via photon-mediated interactions, with elastic and inelastic components. A continuous laser drive excites the atoms on-resonance. Atoms also spontaneously emit photons into free-space. Credit: Steven Burrows/Rey Group

Sanaa Agarwa, Edwin Chaparro, Diego Barberena, A. Piñeiro Orioli, G. Ferioli, S. Pancaldi, I. Ferrier-Barbut, A. Browaeys, and A.M. Rey. " Directional Superradiance in a Driven Ultracold Atomic Gas in Free Space." PRX Quantum, 5(4), 040335, 2024.

Written by Kenna Hughes-Castleberry

Humans of JILA: Jake Higgins

Among the brilliantly technical and creative minds JILA is home to, postdoctoral researcher Jake Higgins applies the best of both worlds to their work in the group of JILA and NIST Fellow and University of Colorado Boulder physics professor Jun Ye. Leveraging their multi-disciplinary background, Higgins is advancing nuclear clock technology.

In their undergraduate studies at Hendrix College, Higgins majored in Chemical Physics.

“I spent about two thirds of my major there studying chemistry, and a third physics. I’ve been straddling the line between the two subjects since then,” they add.

Drawn to institutions where they could indulge their multi-faceted interests, Higgins nurtured their continued growth in graduate school at the University of Chicago. There, Higgins studied excited state energy transfer dynamics in molecules, ultimately discovering a way to unravel dynamics in nonlinear spectra under professor Greg Engel. This NSF-GRFP supported work is central to understanding how nature optimizes photosynthetic systems.

JILA postdoctoral researcher Jake Higgins
Credit: Kenna Hughes-Castleberry

"There were lots of great ultrafast spectroscopists at UChicago, but many of them were quite different in their style and approach,” notes Higgins. “They were all impactful in their own way. It was great to be raised in an environment where I saw a large parameter space of successful types of scientists.”

Having gained spectroscopic expertise in the realm of biophysics and molecular spectroscopy, in addition to their appreciation for different approaches to research, Higgins sought a postdoctoral position where their array of technical skills could grow.

“In experimental work, sometimes you find very engineering-minded people who build amazing things, [but] sometimes get stuck in the weeds,” they say. “On the other end, there are very creative people who are ready to execute step 5,000, but don’t know what to do for steps two and three.” Higgins found JILA to be place where these camps come together—ideal for refining their own skills.

In Ye’s group, Higgins is part of the team that recently measured the thorium-229 nuclear clock transition. The team had to employ a range of skills and knowledge of fields—including solid state, strong field, and nuclear physics—to make the thorium clock tick. “This project does have a lot of multidisciplinary components, and it’s been surprising to find times where my previous work applied to this problem," Higgins adds. "This project is very fun because we're experts on some components like the laser system, but we're kind of novices at other parts of the project such as nuclear theory.”

As an endeavor that demands breadth of expertise, the thorium nuclear clock also has the potential for breadth of application such as precision time keeping, quantum sensing, and more.

“With a bit more work on our measurement, we might soon access questions in fundamental physics like the variation of the fine structure constant,” adds Higgins.

At JILA, Higgins has continued giving back to their community, where they co-founded the JILA Postdocs Group alongside Rachael Merritt. The postdocs of JILA group regularly organizes events aimed at professional development and community building for the other postdoctoral researchers within the institute.

“I’ve had to be more resilient than maybe I should have had to have been,” they say. "One thing I’m hoping to do in my academic career is be a space for people to show up as themselves.”

Written by Willa Arthur-Dworschack, CU Boulder Graduate Student and SCO mentee

JILA News and Awards

News

*JILA and the University of Colorado Boulder Physics Department are to Co-Host the Upcoming CU*IP Conference in January 2025.* This three-day event focuses on talks, workshops, and community building for undergraduate women and gender minorities in physics. As part of the American Physical Society's Conferences for Undergraduate Women and Gender Minorities in Physics (CU*IP), the conference aims to support and inspire students to continue in the field.

JILA and NIST Fellow and CU Boulder Physics Professor Jun Ye is Featured in New NOVA Documentary. In a recently released NOVA documentary called "Decoding the Universe: Quantum," JILA and NIST Fellow and CU Boulder physics Professor Jun Ye brings his expertise to the screen, unveiling the mysteries of quantum mechanics and atomic clocks. This captivating program takes viewers on a journey into the “quantum universe,” where particles defy traditional physics, spinning in two directions simultaneously and interacting across vast distances. Ye’s research on atomic clocks demonstrates the transformative potential of precision timekeeping in shaping future quantum technologies.

JILA Launches Innovative Research Professional Development Program. JILA has officially launched its new Research Professional Development Program, an initiative designed to provide graduate students and postdoctoral researchers with comprehensive skills beyond their core scientific training. Focusing on leadership, mentorship, big-picture thinking, and equity in research environments, this program aims to equip participants with the tools they need to become successful scientific leaders.

JILA Hosts Another Successful Life After JILA Alumni Mixer, Bringing Together Current and Former JILAns. On November 7, 2024, the Rayback Collective in Boulder hosted 65 current and former members of the JILA community gathered for the Life After JILA alumni mixer. The event, now managed by the JILA Association of Graduate Students (JAGS), offered an evening of reconnection, networking, and celebration of JILA's rich history and community.

A photo from the first session of JILA’s new Research Professional Development Program, taught by Dr. Ellen Keister, Director of Education for STROBE.
Credit: Christine Jackson/JILA

Awards

JILA and NIST Fellow and University of Colorado Physics Professor Jun Ye Recognized as a 2024 Highly Cited Researcher. Jun Ye has been named a 2024 Highly Cited Researcher by Clarivate. This distinction is awarded to scientists whose work ranks in the top 1% of citations globally.

JILA Associate Fellow and CU Boulder Physics Assistant Professor Shuo Sun Receives NSF CAREER Award for Quantum Internet Research. Sun received this award for his research proposal, “Developing a High-Dimensional Photonic Quantum Register for the Quantum Internet.”

JILA-Based Innovation Team Flari Tech Wins CU Boulder’s 2024 Lab Venture Challenge for Breakthrough Breath Diagnostic Technology Targeting Lung Cancer. Flari Tech Inc., a startup rooted in cutting-edge JILA research, has clinched one of the prestigious 2024 Lab Venture Challenge (LVC) grants from CU Boulder build a breathalyzer for diagnostics use targeting life-threatening diseases such as lung cancer.

JILA is a joint institute of the University of Colorado Boulder and the National Institute of Standards and Technology

University of Colorado **Boulder**

National Institute of Standards and Technology
U.S. Department of Commerce

About JILA

JILA was founded in 1962 as a joint institute of CU-Boulder and NIST. JILA is located at the base of the Rocky Mountains on the CU-Boulder campus in the Duane Physics complex.

JILA's faculty includes two Nobel laureates, Eric Cornell and John Hall, as well as two John D. and Catherine T. MacArthur Fellows, Margaret Murnane and Ana Maria Rey. JILA's CU members hold faculty appointments in the Departments of Physics; Astrophysical & Planetary Science; Chemistry; Biochemistry; and Molecular, Cellular, and Developmental Biology, as well as in the School of Engineering.

The wide-ranging interests of our scientists have made JILA one of the nation's leading research institutes in the physical sciences. They explore some of today's most challenging and fundamental scientific questions about quantum physics, the design of precision optical and x-ray lasers, the fundamental principles underlying the interaction of light and matter, and processes that have governed the evolution of the Universe for nearly 14 billion years. Research topics range from the small, frigid world governed by the laws of quantum mechanics through the physics of biological and chemical systems to the processes that shape the stars and galaxies. JILA science encompasses eight broad categories: Astrophysics, Atomic & Molecular Physics, Biophysics, Chemical Physics, Laser Physics, Nanoscience, Precision Measurement, and Quantum Information Science & Technology.

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