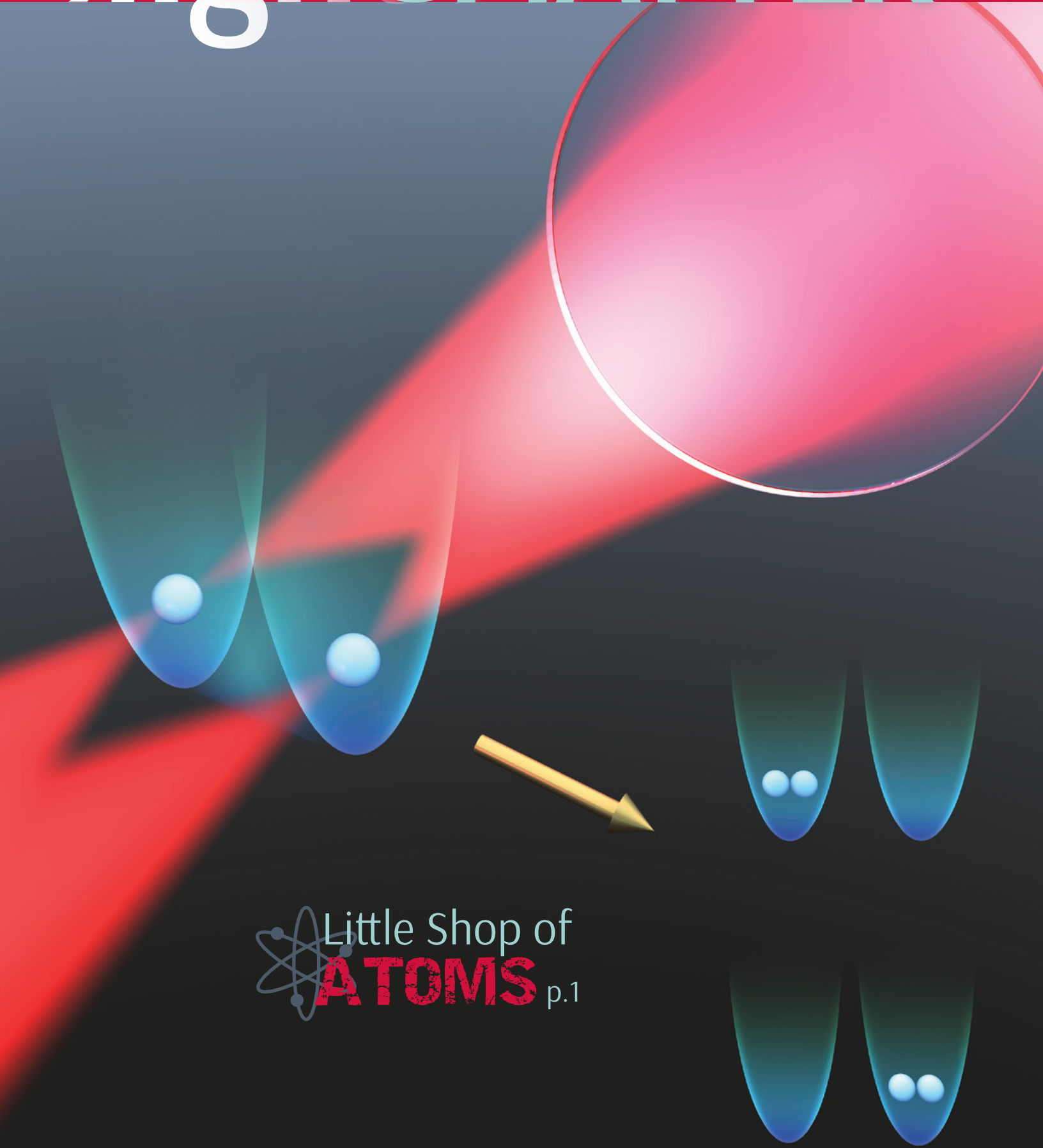


JILA light & MATTER

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Little Shop of
ATOMS p.1



The Instrument Shop's annual brat cookout was a real "hit" on a hot July day.

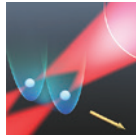
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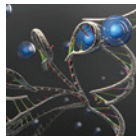
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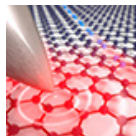
Little Shop of Atoms **1**



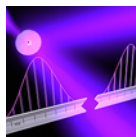
Sky Clocks and the World of Tomorrow **3**



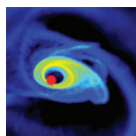
Crowd Folding **5**



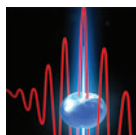
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Little Shop of ATOMS

Graduate student Adam Kaufman and his colleagues in the Regal and Rey groups have demonstrated a key first step in assembling quantum matter one atom at a time.



Kaufman accomplished this feat by laser-cooling two atoms of rubidium (^{87}Rb) trapped in separate laser-beam traps called optical tweezers. Then, while maintaining control over the atoms to be sure they were identical in every way, he moved the optical tweezers closer and closer until they were about 600 nm apart. At this distance, the trapped atoms could “tunnel” their way over to the other laser-beam trap if they were so inclined.

The researchers wondered what would happen next. After all, the individual atoms are so small that they actually can interfere like waves. Plus, the ^{87}Rb atoms were bosons. And, bosons are particles that can occupy exactly the same quantum state at ultralow temperatures and form a tiny Bose-Einstein condensate, or BEC.

Kaufman realized that his atoms might also interfere with each other—just like photons of light. That’s when things got really interesting. Photons, which are also bosons, interfere with one another in a very peculiar way when there are only two of them. Kaufman wanted to find out if his ^{87}Rb atoms would behave in the same way.

A few milliseconds into the experiment, Kaufman observed that even though the two atoms started out trapped in different optical tweezers, they both turned up in either one or the other optical tweezers when he “looked” to see where they were. He also discovered that it was impossible to predict ahead of time which laser-beam trap would get the two atoms.

Interestingly, he almost never found the two atoms in separate optical tweezers. He knew that waves

sometimes cancel each other out—if their crests and troughs line up with each other. Similarly, the possibility of finding one atom in each tweezer disappeared during the experiment because of destructive interference of the matter waves of the two bosons. Kaufman and his colleagues showed that this is exactly what happened.

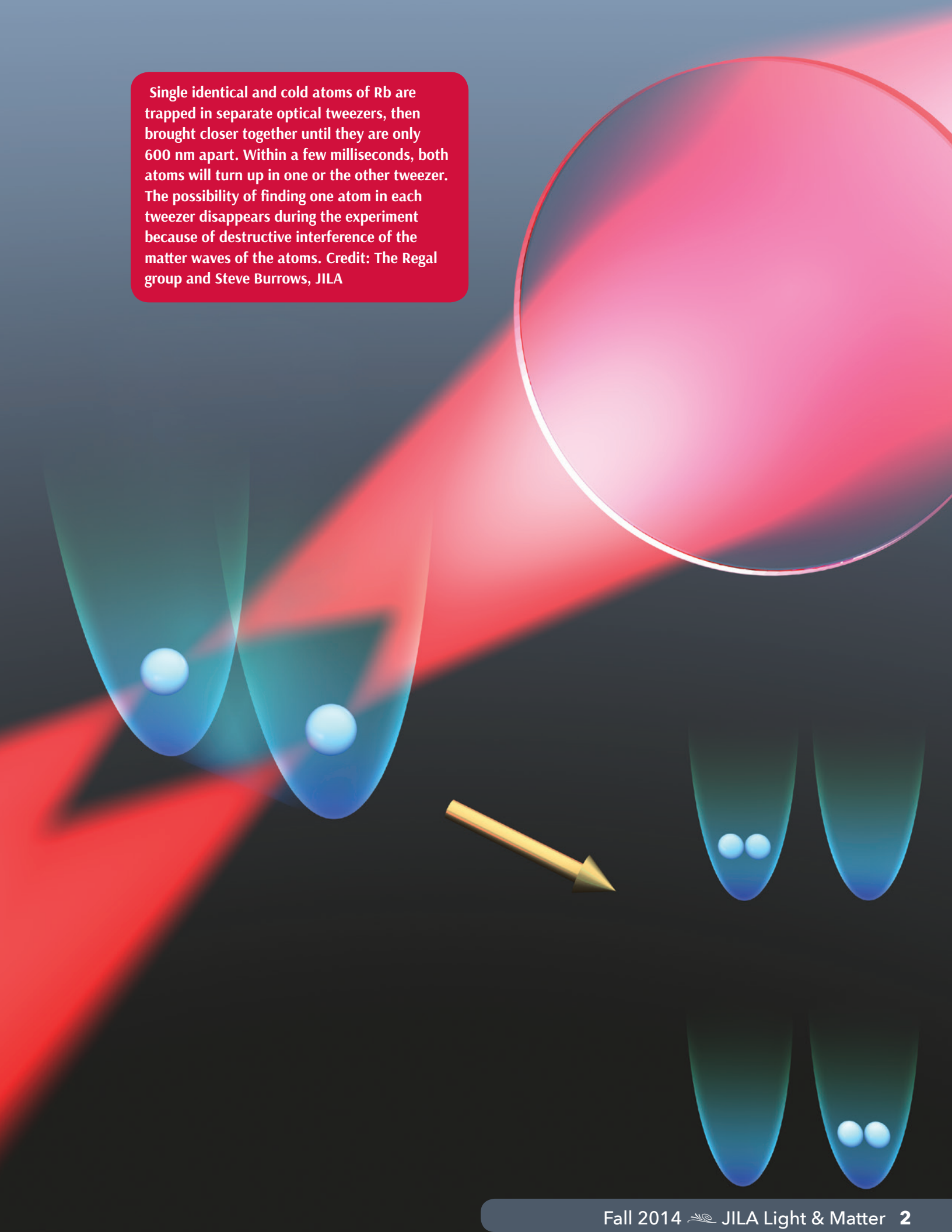
Kaufman showed that exquisite control of the atoms was required to see the destructive interference; anything that allowed someone to tell the difference between the two atoms also destroyed the effect. Hence, the experiment showed that Kaufman is very good at assembling single cold atoms into a two atom quantum structure. This achievement may have profound consequences.

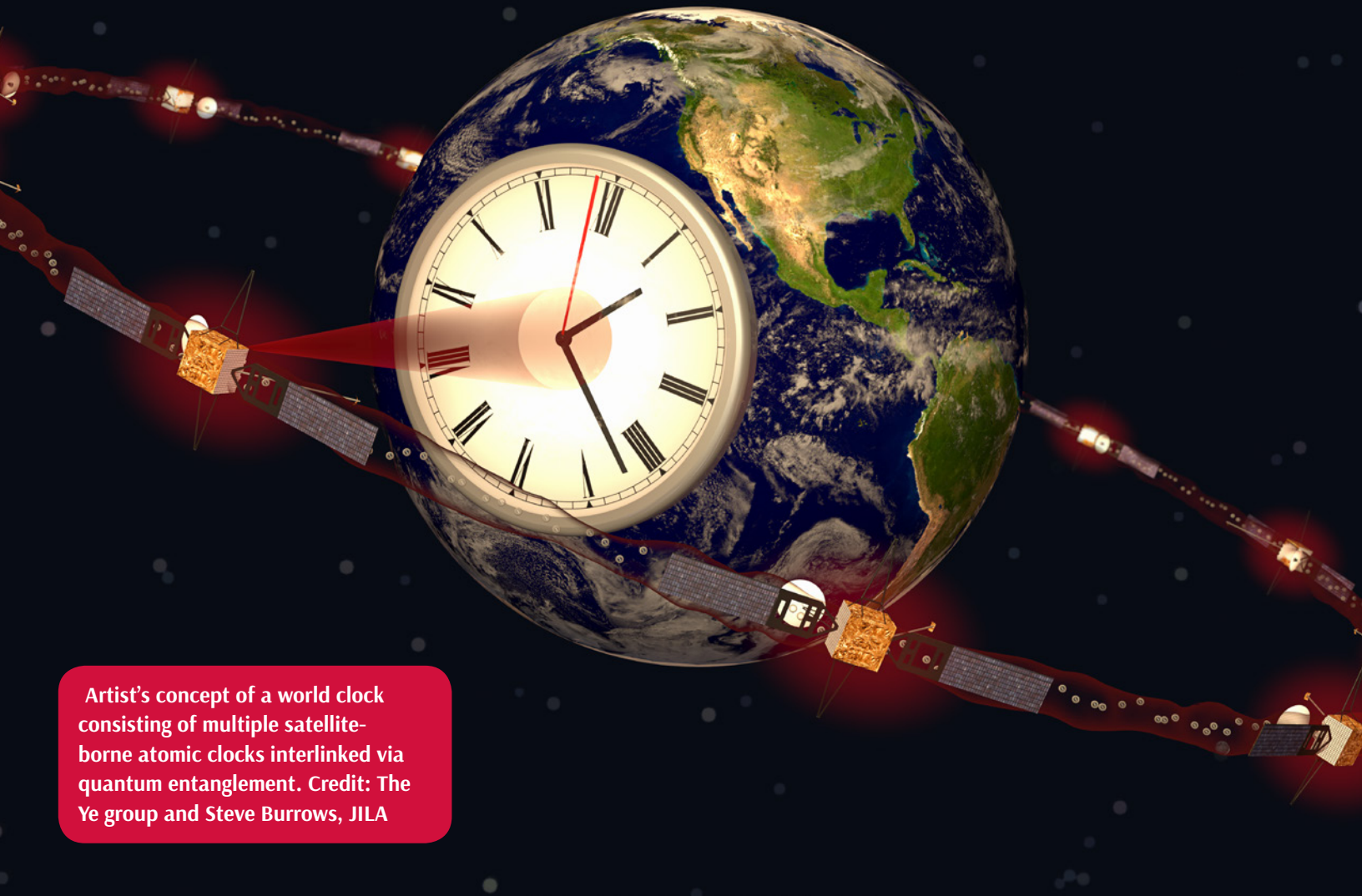
This experiment is the first step in engineering a new quantum system. It may open the door to using single-trapped atoms to assemble BECs or other quantum systems. Designer quantum systems have exciting future prospects, including highly sensitive nanoscale force detection, tiny optical devices based on the control of neutral atoms, and quantum simulators based on laser-cooled atoms.

The little shop of atoms invented by Kaufman and his colleagues is now open for business. His experimentalist colleagues include graduate students Brian Lester and Collin Reynolds as well as Fellow Cindy Regal. The theorists include research associate Michael Wall, former graduate student Michael Foss-Feig, former senior research associate Kaden Hazzard, and Fellow Ana Maria Rey. ✨

A. M. Kaufman, B. J. Lester, C. M. Reynolds, M. L. Wall, M. Foss-Feig, K. R. A. Hazzard, A. M. Rey, and C. A. Regal, *Science*, **345**, 306–309 (2014).

Single identical and cold atoms of Rb are trapped in separate optical tweezers, then brought closer together until they are only 600 nm apart. Within a few milliseconds, both atoms will turn up in one or the other tweezer. The possibility of finding one atom in each tweezer disappears during the experiment because of destructive interference of the matter waves of the atoms. Credit: The Regal group and Steve Burrows, JILA





Artist's concept of a world clock consisting of multiple satellite-borne atomic clocks interlinked via quantum entanglement. Credit: The Ye group and Steve Burrows, JILA

Sky Clocks and the World of Tomorrow

Imagine a network of multiple clocks orbiting the Earth, not only reporting down to us, but also collaborating quantum mechanically among themselves to operate precisely in sync as a single global superclock, or world clock. The world clock is delivering the most precise timekeeping in all of human history—to every member nation regardless of politics, alliances, or behavior on the ground.

Moreover, the world clock itself is virtually immune to sabotage, and it can peer under the surface of the Earth to uncover its detailed composition or out into space to reveal a better understanding of fundamental physical principles such as quantum mechanics and gravity.

Welcome to quantum timekeeping in the world of tomorrow. The necessary ingredient in the design of a world clock is quantum entanglement. Entanglement is what Albert Einstein called “spooky action at a distance.” In a world clock, the atoms in each orbiting clock would not only be entangled with each other, but also with the atoms in the other clocks. What this means is that when something happens to a single atom in this global timekeeping system, all the other atoms in all the clocks would respond. The result would be global timekeeping with unprecedented accuracy and precision limited only by the laws of quantum mechanics themselves.

What’s more, by combining the intricately structured clock network with basic techniques of quantum communication, the world clock would be secure from both internal and external threats. Security measures would include preventing non-member states from eavesdropping on the clock signals and a carefully honed quantum-based strategy for detecting sabotage of individual clocks by member nations. Sabotage would immediately result in the rogue nation being disconnected from the world clock. This would be a serious penalty since the world clock’s primary function would be to control the maintenance and synchronization of national time standards in real time. The national time standards, in turn, are necessary for the control of electric grids, global commerce and stock markets, ground- and space-based observatories, and other activities of modern life.

In addition to helping to smoothly run the world’s advanced technological systems, the world clock may spur advances in earth science research, more precise navigation of space probes, and a better

Entanglement is what Albert Einstein called “spooky action at a distance.” In a world clock, the atoms in each orbiting clock would not only be entangled with each other, but also with the atoms in the other clocks. What this means is that when something happens to a single atom in this global timekeeping system, all the other atoms in all the clocks would respond.

understanding of the fundamental laws of nature, including the theory of relativity and the connection between quantum physics and gravity.

The amazing proposal for a quantum network of sky clocks comes compliments of graduate student Mike Bishof, Fellow Jun Ye, and their colleagues Péter Kómár, E. M. Kessler, and M. D. Lukin of Harvard University, L. Jiang of Yale University, and A. S. Sørensen of the Niels Bohr Institute (Copenhagen). The *Nature Physics* article describing the quantum network of clocks appeared online on June 15, 2014. ✨

P. Kómár, E. M. Kessler, M. Bishof, L. Jiang, A. S. Sørensen, J. Ye, and M. D. Lukin, *Nature Physics* **10**, 582–587 (2014).

Crowd Folding

Biomolecules may not always behave the same way in test tubes as they do in living cells, a fact underscored by important new work by former research associate Nick Dupuis, graduate student Erik Holmstrom, and Fellow David Nesbitt.

The researchers found that under crowded conditions that begin to mimic those found in cells, single RNA molecules folded 35 times faster than in the dilute solutions typically used in test-tube experiments. Crowding also led to a modest decrease in the unfolding rate. The results strongly support the idea that compact structures, such as folded RNA molecules and proteins, may be much more stable in living cells than they are in test tubes, where there's lots of room to stretch out and flop around.

The idea that crowding favors compact structures in cells makes intuitive sense. Imagine trying to make headway through a crowd at a popular concert or sports event. Keeping your arms and possessions close to your body works much better for making headway through a throng of people than waving your arms and packages as far away from your body as possible. The same principles apply to biological activity inside cells. Not surprisingly, the biologically active forms of RNA, proteins, and other important large molecules found in cells are nearly always compact, folded structures.

Dupuis and his colleagues' work on RNA folding under crowded conditions was reported online May 21, 2014 in the *Proceedings of the National Academy of Sciences*.

The Nesbitt group's research was the first to use single-molecule fluorescence techniques to precisely measure the effects of crowding on the rates

of folding and unfolding of individual RNA molecules. With this technique, an RNA molecule fluoresces green when it's unfolded and red when it's folded. Under crowded conditions, the molecule spent a lot less time green because it folded so much more quickly.

The researchers chose long chains of antifreeze molecules (polyethylene glycol, or PEG) as crowding agents because these molecules just take up lots of space. PEG doesn't interact with the RNA in any other way. The crowding is enough to put pressure on the RNA to get smaller. And, it turns out that getting smaller (i.e., more compact) makes it more likely the molecules will go on to fold. Interestingly, once the RNA molecules are folded, they unfold just a little bit more slowly than when they're not crowded. Of course, they don't stay unfolded for long.

Next, the group plans to take bacterial cells and break them open so it can watch RNA folding in a soup of bacterial innards. This soup will be much more like the crowded environment inside cells. It's possible the researchers will learn enough about RNA folding in a bacterial soup to go on to investigate single-molecule RNA folding inside a living cell. ✨

Nicholas F. Dupuis, Erik D. Holmstrom, and David J. Nesbitt, *Proceedings of the National Academy of Sciences USA*, **111**, 8464–8469 (2014).

Until recently, studies of RNA folding and unfolding took place in dilute solutions with lots of room for RNA to move around, as shown here. Interestingly, the Nesbitt group recently showed that the rate of RNA folding increases dramatically under the much-more crowded conditions found in living cells. Credit: The Nesbitt group and Brad Baxley, JILA



The JILA History Crossword

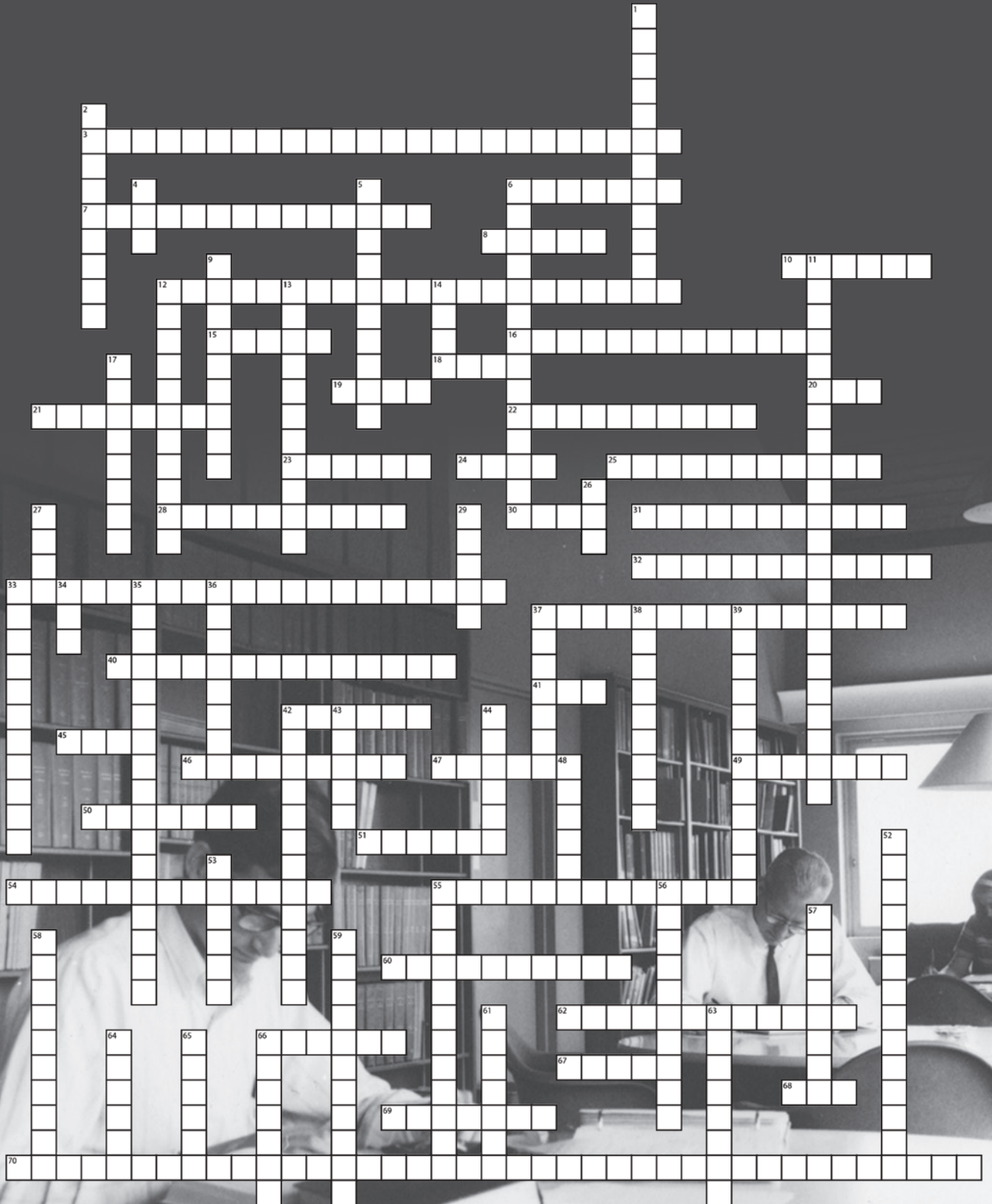
ACROSS

3. Early JILA experiment
6. CU Financial Officer who found financing for first JILA building
7. Both spouses with professional careers
8. Newest JILA building dedicated in 2012
10. Particles occupying same quantum state
12. Maryland institute modeled after JILA
15. Month JILA came into existence
16. JILA co-founder
18. Agency responsible for 14 down
19. JILA Federal co-partner after 1988.
20. Atomic force microscope
21. Temperature of 26 down
22. Genesis author
23. Nobel Laureate Carl _____
24. Controversial study topic of 39 down
25. JILA historian
28. What JILA became in 1990
30. Predicted BEC
31. Housed 30-m long interferometer
32. Honored guest, 1967 dedication of JILA tower
33. Got their act together
37. First female JILA fellow
40. Quantum JILA Fellow
41. Ground-state ultracold molecules
42. Powerful 2011 cluster computer
45. Institute name after 1994
46. First device for measuring wavelength of light
47. 1994 spin-off company
49. Nobel Laureate Eric _____
50. First female JILA chair Katy _____
51. Jeff, the chromosphere modeler, ____
54. JILA Chair 1983-1984
55. CU physics department chair 1962
60. Site of JILA's 10th anniversary dinner
62. First head of JILA machine shop
66. Art retiring in 1990
67. 2007 JILA cluster computer
68. Agency supporting LISA
69. They're in a clock
70. Institute name 1962-1994

DOWN

1. What Jan Hall & NBS colleagues measured in 1972
2. Location of annual staff hike
4. Document leading to the creation of JILA
5. NBS Director who supported creation of JILA
6. JILA co-founder and later NBS Director
9. Ten-story office tower completed in 1967
11. JILA's first home at CU
12. Helped transform global timekeeping
13. CU president when JILA founded
14. Retroreflectors placed there in 1969
17. Internal structure of neutron stars?
26. Superatom of Rb
27. Pete Bender's dream observatory
29. Its length was redefined in terms of the speed of light (1985)
33. JILA inspiration for 34 down
34. JILA Federal co-partner 1962-1988
35. Reflection of laser light off the moon
36. NSF director from 1993 to 1998
37. Optical measurement suite
38. Astronaut Neil placed retroreflectors on moon
39. Distinguished JILA Fellow (1963-1974)
42. Renowned softball team
43. Almost every lab has one
44. SRO's Lorraine _____
48. 1965 CU president Joseph _____
52. Name of JILA NIST division since 1977
53. Supernova Dick _____
55. JILA's second home
56. Iconic signal of 26 down
57. Term of JILA Chairs
58. Probabilistic theory simulations
59. JILAns have won three of these
61. Invisible ruler of light
63. Restaurant hosting first Fellows meeting
64. Primitive 1980s email system
65. Governance rules adopted in 1964
66. Armitage studies the formation of these

* First person to turn in a correct puzzle to SCO wins a \$25 Amazon gift card.



FLAWS

The Raschke group recently came up with a clever way to detect folds and grain boundaries in graphene, a sheet made of a single layer of carbon atoms. Such defects stop the flow of electrons in graphene and are a big headache for engineers working on touch screens and other electronic devices made of this material.



The group has invented a nano sonar-like system that uses infrared (IR) light waves (instead of water waves) to find flaws in graphene. An innovative setup creates a “virtual” optical cavity between an atomic force microscope (AFM) tip and a defect boundary. When the AFM tip emits infrared (IR) light waves across the surface of graphene, the defect boundary reflects them back across the surface to the tip, creating a standing wave. The scattering of the standing wave by the AFM tip is then captured and imaged with an IR nano microscope. The process generates snapshots of the fatal flaws that impede the transport of electrons and light in graphene.

The group recently conducted a detailed analysis of both the amplitude and phase of the IR surface waves in its new detection system. The analysis allowed the researchers to locate flaws in the material that would affect device performance. At the same time, they were able to come up with a simple, straightforward theory to describe the surface waves they measured.

In a test of graphene of the type under development for touch-screen sensors, the group found an unexpectedly large number of boundary defects. This result was a surprise because the sample was supposed to be of high quality, and previous tests had failed to detect similar defects. Nevertheless, it was “back to the drawing boards” for industry engineers—except that now, thanks to the Raschke group, they can use the group’s

relatively simple method to test for boundary defects.

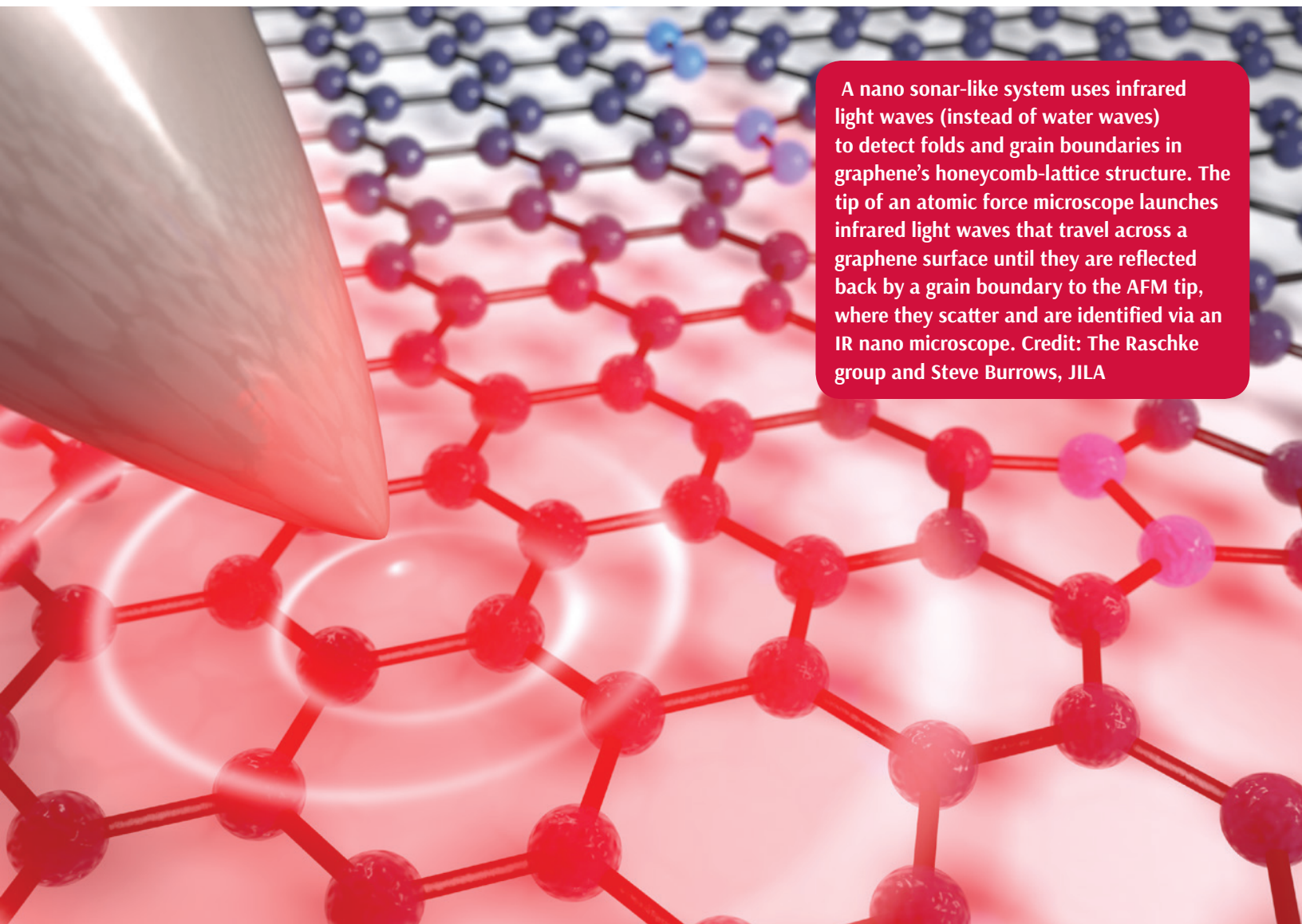
The researchers responsible for this new method include CU undergraduate Justin Gerber (who dreamed up the virtual optical cavity), research associate Sam Berweger, Brian T. O’Callahan, and Fellow Adjunct Markus Raschke.

This work is important because of the high hopes for graphene-based electronics. This ultrathin material is surprisingly strong and flexible. And, it appears to have just the right electronic properties for use in flexible displays, touch sensors, photosensors, and other devices. Researchers are even investigating ways to use graphene to make basic circuit elements such as transistors. However, a serious stumbling block to realizing the potential of graphene is the ability to produce sheets of high enough quality for graphene to live up to its reputation.

The new technique developed by the Raschke group is an important step in this direction because it can detect folds and grain boundaries both before and after graphene is made into a device. Plus, the surface waves used in the technique may also lead to applications for future high-speed electronics.

Justin A. Gerber, Samuel Berweger, Brian T. O’Callahan, and Markus B. Raschke, *Physical Review Letters* **113**, 055502 (2014).

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A nano sonar-like system uses infrared light waves (instead of water waves) to detect folds and grain boundaries in graphene's honeycomb-lattice structure. The tip of an atomic force microscope launches infrared light waves that travel across a graphene surface until they are reflected back by a grain boundary to the AFM tip, where they scatter and are identified via an IR nano microscope. Credit: The Raschke group and Steve Burrows, JILA

Invisible Rulers of Light

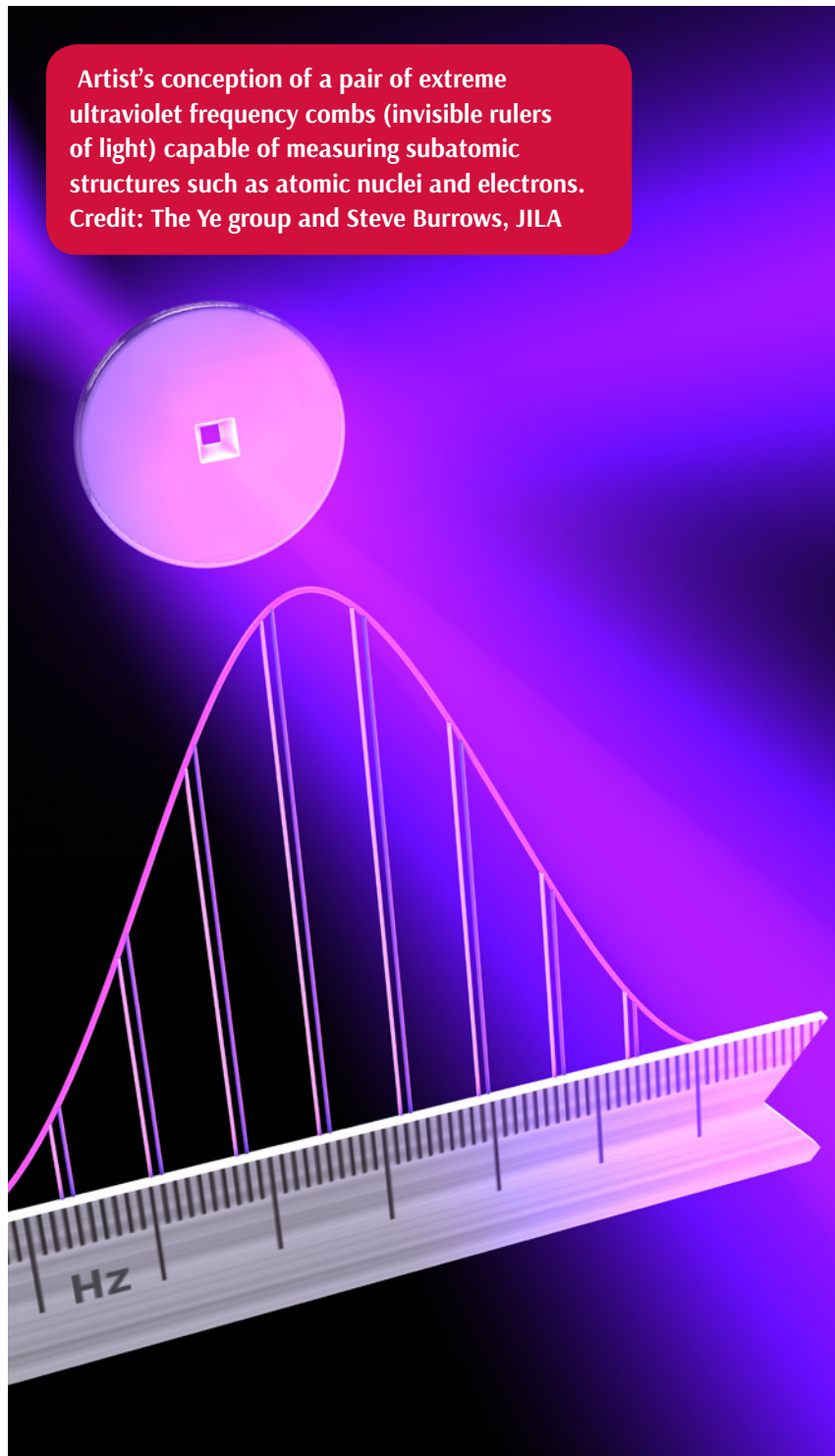
The Ye group has not only made two invisible rulers of extreme ultraviolet (XUV) light, but it also figured out how to observe them with ordinary laboratory electronics. With this setup, the researchers were able to prove that the two rulers had extraordinarily long phase-coherence time. This feat is so profound, it is nearly certain to transform the investigation of matter using extreme ultraviolet light, according to Ye's colleagues in precision measurement and laser science. This research was reported online in *Nature Photonics* on June 22, 2014.

The invisible rulers of light are a pair of XUV-frequency comb lasers that work in tandem. A frequency comb is a light source whose spectrum consists of a series of equally spaced "teeth," which are like the ticks on a ruler, except that they measure frequency and are much closer together. The invention of the optical frequency comb in 2000 has already transformed precision measurement with visible light. The same transformation is now set to happen with XUV wavelengths of light (124-10 nm). It's not surprising this advance occurred in the Ye labs, where the new work could increase the spectral resolution of any XUV source by 10-million-fold.

"What's real is what you measure if you're measuring well," says Fellow Jun Ye. "And, now what we can measure precisely with visible light, we can do just as well in the extreme ultraviolet. We hope that one day we will be able to shine XUV comb light on nuclear matter and change its states!"

The team responsible for this stellar advance in precision measurement includes graduate

Artist's conception of a pair of extreme ultraviolet frequency combs (invisible rulers of light) capable of measuring subatomic structures such as atomic nuclei and electrons. Credit: The Ye group and Steve Burrows, JILA



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precisely with visible light, we can do just as well in the extreme ultraviolet. We hope that one day we will be able to shine XUV comb light on nuclear matter and change its states!”

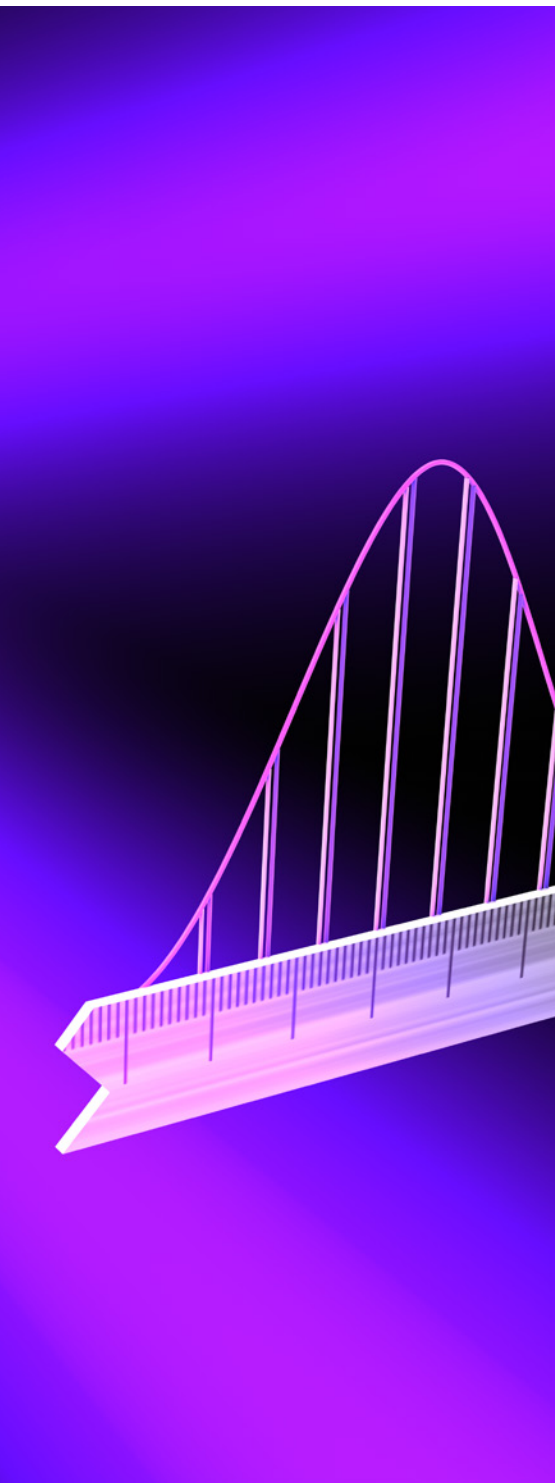
student Craig Benko, former research associates Tom Allison (Stony Brook University) and Arman Cingöz (AOSense), research associates Linqiang Hua and François Labaye, former graduate student Dylan Yost (Colorado State University) and Fellow Jun Ye.

The pair of XUV combs will be able to make precision measurements of atomic nuclei, atoms, charged ions, and simple molecules. Such measurements require XUV laser light that is coherent and stable. Until now, it wasn’t clear that there would ever be a ruler of light in the XUV frequencies like there is in the visible.

Since no person or machine can “see” XUV frequency-comb teeth, the XUV comb teeth are detected via “beating” together two combs, resulting in precisely and evenly spaced electronic “beat notes” observable with laboratory electronics. The beat notes occur when the two lasers are slightly offset from one another in frequency, but overlapped in space and time. The lasers are then detected simultaneously, which causes the beat notes to appear.

Because the invisible rulers of light can now be “seen” and precisely measured, new research is on the horizon. Such research includes precision nuclear clocks based on transitions in an atomic nucleus, nuclear isotope selection, precise studies of electron behavior in atoms and molecules subject to intense light fields, and the ability to resolve features of matter that are too small to be seen with an ordinary microscope. And, unlike producing XUV radiation with a synchrotron, which requires many researchers to operate, it only takes a couple of researchers to do an experiment with a pair of XUV lasers in a laboratory!✱

Craig Benko, Thomas K. Allison, Arman Cingöz, Linqiang Hua, François Labaye, Dylan C. Yost, and Jun Ye, *Nature Photonics* **8**, 530–536 (2014).



When You Feast Upon a Star

It makes a difference where you are

A Be star is a luminous, blue B-type star with distinctive spectral lines that can provide two types of feasts—tasty snacks or full-scale banquets—for a former companion star in a binary system. The feasting begins when the companion star goes supernova and becomes a neutron star or, more rarely, a black hole. Typically, the companion blows up with enough force to kick itself into an eccentric (elliptical) orbit that is misaligned with respect to the Be star's orbit.



Such skewed orbits, in particular their misalignment, help determine what kind of feast the surviving Be star delivers at any given time. The other factor at play is the intrinsic nature of the Be star itself. Be stars are among the most massive of stars. They are so large and rapidly spinning, in fact, that they spontaneously lose mass and form decretion disks in orbit around them.

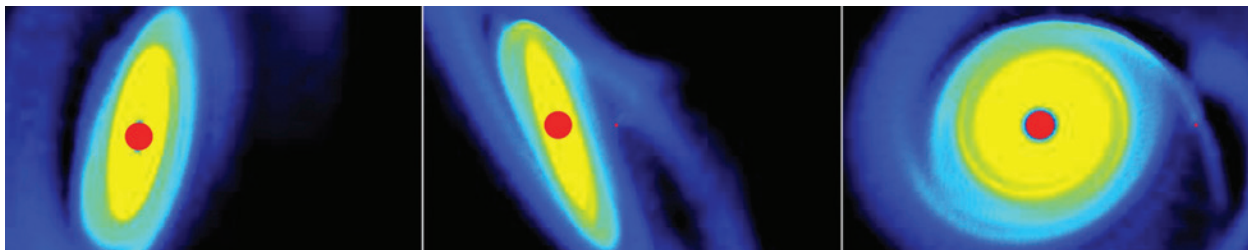
Every time the neutron star makes a close approach to the Be star's decretion disk, it enjoys a delicious snack of stardust. The neutron star belches outbursts of X-rays in appreciation. Astrophysicists call these emissions Type I X-ray outbursts. Type I X-ray outbursts can occur during every orbit of a neutron star around a Be star.

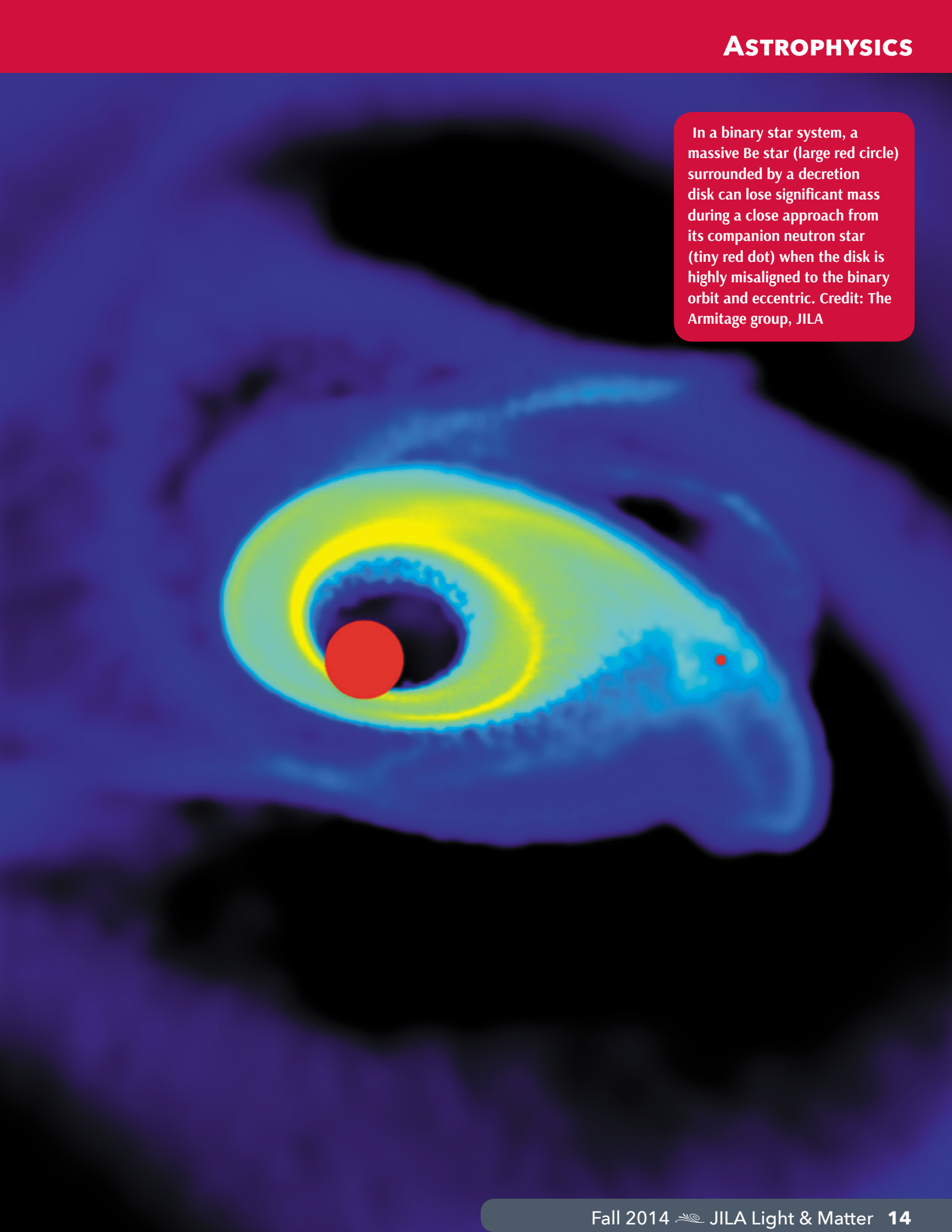
However, much less frequently, something different occurs. According to new theoretical work by the Armitage group and colleagues at JILA and elsewhere, the decretion disk around the Be star becomes so eccentric and misaligned that the

neutron star is able to grab a whole lot of stardust from the Be star's decretion disk. In fact, the neutron star steals so much of the Be star's disk that an accretion disk forms around neutron star, as shown in the picture. The neutron star feasts off its newly formed accretion disk for weeks or even months, belching X-rays the entire time. Astrophysicists refer to these extended events as giant (Type II) outbursts.

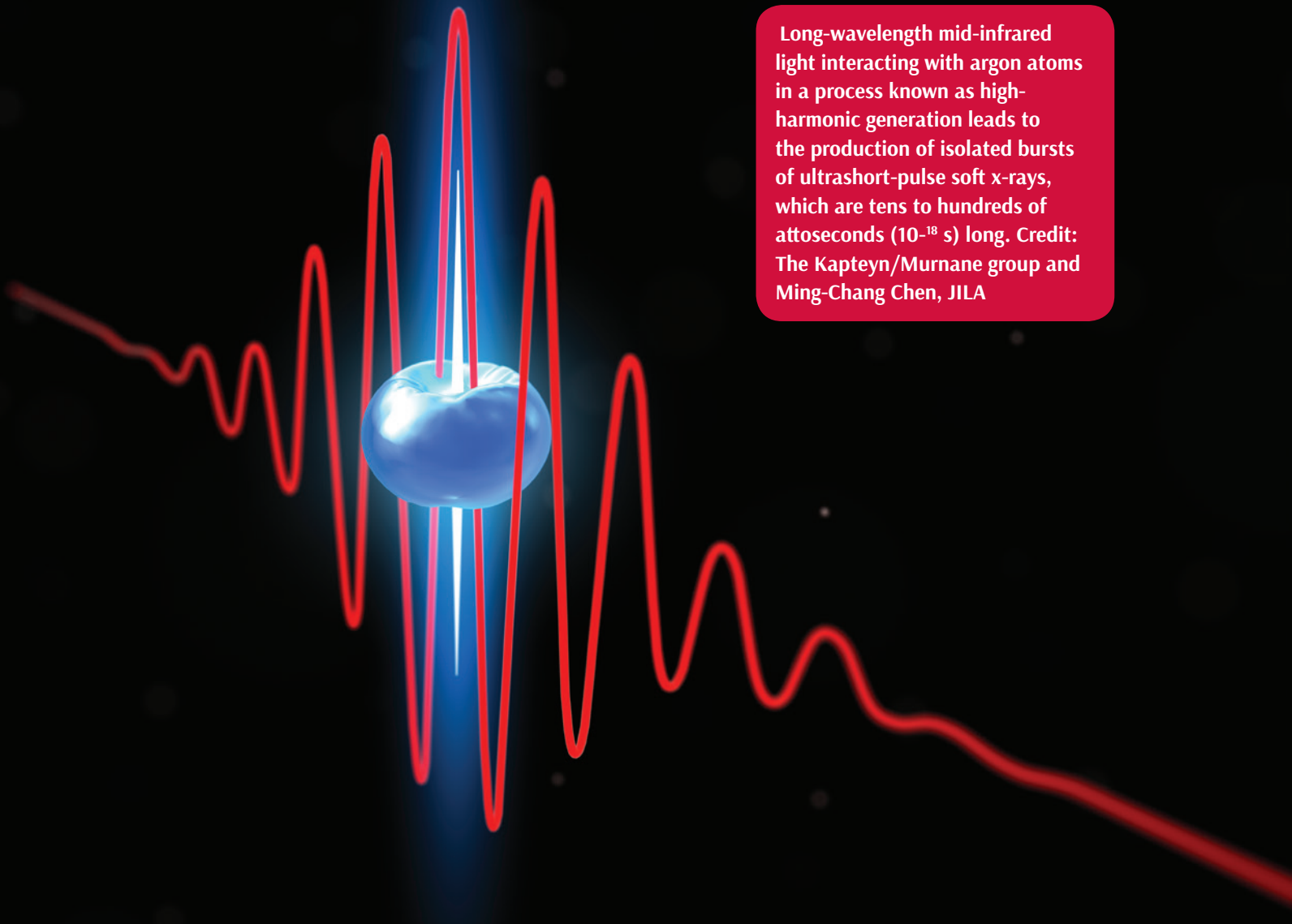
Type II outbursts (i.e., full-scale banquets) can only occur when the Be star's disk is both misaligned with the orbit of its companion and eccentric. The researchers responsible for clarifying the alimentary behavior of Be star/X-ray binaries include research associates Rebecca Martin and Chris Nixon, Fellow Phil Armitage, and their colleagues from the Space Telescope Science Institute in Maryland and Monash University in Australia. ✨

Rebecca G. Martin, Chris Nixon, Philip J. Armitage, Stephen H. Lubow, and Daniel J. Price, *The Astrophysical Journal Letters* **790**, L34 (2014).





In a binary star system, a massive Be star (large red circle) surrounded by a decretion disk can lose significant mass during a close approach from its companion neutron star (tiny red dot) when the disk is highly misaligned to the binary orbit and eccentric. Credit: The Armitage group, JILA



Long-wavelength mid-infrared light interacting with argon atoms in a process known as high-harmonic generation leads to the production of isolated bursts of ultrashort-pulse soft x-rays, which are tens to hundreds of attoseconds (10^{-18} s) long. Credit: The Kapteyn/Murnane group and Ming-Chang Chen, JILA

The **Long** and the **Short** of **Soft X-rays**

Mid-infrared (mid-IR) laser light is accomplishing some remarkable things at JILA. This relatively long-wavelength light ($2\text{--}4\ \mu\text{m}$), when used to drive a process called high-harmonic generation, can produce bright beams of soft x-rays with all their punch packed into isolated ultrashort bursts. And, all this takes place in a tabletop-sized apparatus.

The soft x-ray bursts have pulse durations measured in tens to hundreds of attoseconds (10^{-18} s).

Until now, attosecond pulses were limited to the extreme ultraviolet (XUV) region of the spectrum. However, these XUV attosecond pulses don't penetrate most materials, liquids, and complex molecular systems. In contrast, soft x-ray attosecond pulses can penetrate many materials and liquids. Hence they promise to expand the field of attosecond science. Because attosecond soft x-ray bursts can now be readily made in a research laboratory, they will open the door to observing the intricate dance of electrons inside atoms, molecules, liquids, and materials.

A report of the generation of the first attosecond soft x-ray bursts appeared online in the *Proceedings of the National Academy of Sciences, USA*, May 21, 2014. The international team of researchers responsible for this feat included Ming-Chang Chen (National Tsing Hua University), graduate students Chris Mancuso, Ben Galloway, and Dimitar Popmintchev, research associates Carlos Hernández-García and Franklin Dollar, as well as Pei-Chi Huang (National Tsing Hua University), Barry Walker (University of Delaware), Luis Plaja (Universidad de Salamanca), Fellows Andreas Becker, Margaret Murnane, and Henry Kapteyn, and senior research associates Agnieszka Jaroń-Becker and Tenio Popmintchev.

Theorists and experimentalists working together hand in hand were able to learn to create bursts of attosecond soft x-rays via high harmonic generation, a method that has been used extensively and effectively by the Kapteyn/Murnane group. In high harmonic generation, x-rays are produced when electrons are first plucked from argon atoms by a mid-IR laser and then smashed back into their parent ions when the oscillating field of the laser reverses (like the motion of a boomerang). The atoms then naturally emit their excess energy as isolated bursts of soft x-rays. (These harmonics of laser light are like the audible overtones that

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you can hear when a piano key or guitar string is struck hard.)

The fact that the high harmonics emerged as isolated attosecond bursts of soft x-rays was a beautiful confirmation of theory work that suggested that making attosecond pulses in the soft x-ray region might be possible. But, until the experimental physicists could actually measure the pulses, this theory could not be tested. However, measuring these pulses was no small feat. First, the attosecond pulse had to be split into two parts. Then a special beam separator had to delay part of the pulse (by a distance of just 0.5 nm) so the two parts could interfere with each other, creating a short burst of soft x-ray light. ✨

Ming-Chang Chen, Christopher Mancuso, Carlos Hernández-García, Franklin Dollar, Ben Galloway, Dimitar Popmintchev, Pei-Chi Huang, Barry Walker, Luis Plaja, Agnieszka A. Jaroń-Becker, Andreas Becker, Margaret M. Murnane, Henry C. Kapteyn, and Tenio Popmintchev, *Proceedings of the National Academy of Sciences USA* 111, E2361–E2367 (2014).

How Did They Get Here?

Konrad Lehnert was born in Bogota, Colombia, where his father was managing a plant for the Phillips Petroleum Company. Lehnert moved with his family (including an older brother born in Cali, Colombia) back to the United States at age four. At the time, he was fluent in Spanish, but the language faded as he grew up in Bartlesville, Oklahoma, the world headquarters of the oil company.

Lehnert spent a couple of years with his family in Brussels, Belgium, during a second extended business assignment. However, his parents had grown frustrated with the language confusion that resulted from the relocation back to the states from Colombia, so they sent their boys to the English-speaking International School of Brussels rather than to a local school where classes were conducted in French.

Lehnert's father, an engineer by training, sparked his young teenage son's interest in science by bringing home popular science books, including John Gribbin's *In Search of Schrödinger's Cat: Quantum Physics and Reality*, which Lehnert remembers reading along with *Timewarps and Spacewarps*. The latter books introduced Lehnert to some of Einstein's exotic thinking about the nature of the world.

By the time he was ready for college, Lehnert had become more practically minded. He knew he was good at math, so he thought he'd like to be an engineer. He was really excited after visiting Harvey Mudd College in Claremont, California, because everyone he met, including the juniors and seniors, was really excited about science and engineering. Plus there were all kinds of nerdy people at Mudd. A self-described "garden-variety nerd" who wasn't very athletic and loved science fiction books, Lehnert thought he'd feel right at home there.

He started college as an engineering major with the goal of becoming an electrical engineer. Engineering itself (but not the course work) was easy and fun, and the idea of electrical engineering seemed terribly modern and futuristic. However, after his sophomore year, he switched his major to physics because he was much more excited about taking physics classes than engineering classes.

When it was time for a senior project, instead of doing laboratory research in physics, Lehnert opted for an engineering project. He worked for Lockheed-Martin on modifying military aircraft to jam broadcasts. The goal was to be able to continue to broadcast while listening to everybody else's broadcasts that were being jammed. Lehnert admits he didn't make a lot of progress on the project, but it spurred an interest in microwave and rf technologies that continues to this day.

Even though he was still straddling the fields of engineering and physics during this project, he found Johnson noise far more interesting than most electrical engineers did. Johnson noise is present in every resistor, but to know the power present in the noisy fluctuations, all one needs to know is the temperature. That Johnson noise excited Lehnert was a pretty good indication that he'd be better cast as a physicist than as an engineer, even though it would take him a little more time to figure this out.

Lehnert graduated with honors from Harvey Mudd in 1993, still imagining that he wanted to be an electrical engineer. So, he spent a year working as an analog and rf designer for a cell phone company (Pacific Communications Sciences Incorporated) in San Diego, California. Most days, he sat



at a large computer terminal and drew symbolic representations of electric circuits. He made circuits that really worked in the microwave cell-phone frequency range. It was fun for a little while, but he just couldn't see doing it for 30 years. In 1994, after a year on the job, Lehnert went to graduate school in physics at the University of California at Santa Barbara (UCSB).

At the time, the UCSB physics program was well positioned to go from a kind of sleepy place to being a very good place in a short amount of time, which was a stroke of good luck for Lehnert. He worked with Professor S. James Allen on the nonequilibrium dynamics in superconductor-semiconductor-superconductor junctions. The project moved slowly, but it finally succeeded after Lehnert had the novel idea of introducing microwave technology into the experiment he was doing. His graduate research also led to the realization that he loved exploring the underlying physics of electrical systems. He earned his Ph.D. in physics in 1999 and headed east to Yale.

Lehnert did postdoctoral research with Robert Schoelkopf, a new professor in Yale's Department of Applied Physics. It took the group about 18 months to build a whole lot of complicated lab equipment and get it working. Initially there were few results; however, the next year was extraordinarily productive. Lehnert worked with his advisor on building superconducting electrical circuits. They figured that if they learned to wire these circuits and keep them cold enough to maintain their quantum mechanical properties, the circuits might be useful for building a quantum computer. After two years, the two came up with some of the newest and most exciting results in the field—just as Lehnert needed to start looking for a job.

Lehnert's job search was fairly traditional. He applied to multiple positions advertised in *Physics Today*, including one from JILA. He was intrigued by JILA because it wasn't quite a government lab, and it wasn't exactly a university. It seemed like a relatively great place to work that had managed to incorporate some of the best aspects of both its parent institutions. So, despite garnering multiple offers, he found JILA's the most appealing.

Lehnert became a NIST Associate Fellow of JILA in December of 2002 and was promoted to Fellow in 2007. His favorite part of being at JILA is his collaboration with CU Associate Fellow Cindy Regal's group. During her training, Regal had spent time in Lehnert's lab as a postdoc. Together, they started a project that has evolved into a collaborative effort to create a coherent, efficient, and bidirectional conversion link between microwave and optical light. A proof of principle experiment of the new converter was successfully carried out in 2013. The experiment has demonstrated how scientifically productive a good working collaboration can be.

Lehnert is a big fan of collaboration as a strategy for fostering innovation in science. For instance, he's part of a new collaborative search for the axion, a hypothetical subatomic particle that scientists hypothesize may constitute dark matter. Lehnert is contributing technology developed in his lab for virtually noiseless amplifiers to the collaboration, which also includes researchers from Yale, the University of California at Berkeley, and the Lawrence-Livermore National Laboratory. The new experiment uses a very cold metal box, or cavity, to look for microwave photons with a particular set of properties. Such photons would only exist inside the cavity if axions were present. Lehnert's role in the experiment is the precision measurement of microwave photons in the cavity, something he does exceptionally well.

Lehnert likes to wander into creative places in the borders between scientific disciplines. He's open to unanticipated events guiding his research in new directions. For instance, when he was asked to join the new axion experiment, he jumped onboard enthusiastically. Dark matter has always been a profound unknown in science, and thus an extremely attractive research focus.

Lehnert is married to Kate Houck, whose background is project management for start-ups in Boulder. The couple enjoys living in Boulder and exploring the nearby Rocky Mountains.

In 2007, Lehnert was a finalist for the Service to America award. He was a Kavli Fellow in 2010 and 2011. He is a Fellow of the American Physical Society.

To read other online bios, visit <http://jila.colorado.edu/faculty/profiles-science>

IN THE NEWS

JUN YE & DEBBIE JIN NAMED "MOST INFLUENTIAL SCIENTIFIC MINDS 2014"

A newly released report from Thomson Reuters on "The World's Most Influential Scientific Minds 2014" includes JILAns Jun Ye and Debbie Jin. The selection of scientists for the report was based on an analysis of Web of Science and InCites citation reports for an 11-year period to identify those researchers who published the highest impact work from 2002-2012 and 2012-2013. The report concludes that these individuals are "influencing the future direction of their fields, and of the world."

DEBORAH JIN AWARDED ISAAC NEWTON MEDAL

Deborah Jin has won the 2014 Isaac Newton Medal, the highest accolade given by the Institute of Physics. She was cited for her experimental work in laser cooling atoms. This work has led to the practical demonstration of universal laws that underpin fundamental quantum behavior.

"Professor Jin is an outstanding, clever, creative scientist," said Prof. Ed Hinds of the Imperial College London. "Her incredibly complex experiments have significantly advanced our understanding of the behavior of electrons in materials. Through her laser cooling of atoms, she has shown that half-integer spin fermions can be coupled to behave like full integer spin bosons.

"These fermion condensates and the work that she has undertaken on extremely cold polar molecules have helped us go deep into the quantum world, a world that we're only just starting to understand in complex many-body systems. Her work is likely to lead to profound advances in measuring and sensing, as well as quantum computing."

The IOP citation states that "ultracold Fermi gases now represent one of the major activities in all of atomic physics, an activity where Jin remains the leader and pioneer."

A selection of news, awards, and what is happening around JILA

TOM PERKINS RECEIVES ARTHUR S. FLEMMING AWARD

Thomas Perkins received the 2013 Arthur S. Flemming Award at a Washington, D. C., ceremony on June 9, 2014. The award was one of 12 given this year to honor outstanding Federal employees in their first 15 years of Federal service. Dr. David Bray, Chief Information Officer for the Federal Communications Commission and a 2012 Flemming Award winner, was the keynote speaker at the event.

"It was a wonderful surprise to receive a 2013 Arthur S. Flemming award," Perkins said. "It is an honor to join such a distinguished group of federal employees, including many JILA/NIST colleagues. I am thankful to my group for all their hard work that made it possible and to NIST management for taking the time to recognize individual scientists."

Perkins joins JILAns David Nesbitt (1991), Debbie Jin (2003), and Jun Ye (2005) as well as Lewis Branscomb, Pete Bender, David Hummer, and Steve Leone as a winner of this prestigious award.

The Arthur S. Flemming Awards were established by the Downtown Jaycees in 1948 to recognize outstanding performance in all areas of the Federal service. Notable past award recipients include Daniel Patrick Moynihan, John Chancellor, Neil Armstrong, Elizabeth Dole, and Nobel Laureate William Phillips of NIST Gaithersburg. More than 500 individuals have received this award since it was established.

Support for the Flemming Awards is provided by Federal Management Systems, Inc. and the Trachtenberg School of Public Policy & Public Administration at the George Washington University.

GREG SALVESEN WINS R. N. THOMAS AWARD

Graduate student Greg Salvesen is the winner of the 2014 R. N. Thomas Award. The award of about \$500 comes from a fund established by Nora Thomas, the widow of JILA co-founder Dick Thomas. In addition to the monetary award, Salvesen received a book about Thomas' exemplary career in astrophysics.

Salvesen is a fifth-year graduate student in Astrophysical and Planetary Sciences. He works under Fellow Mitch Begelman, who says "he is one of the most independent students I have encountered, working in observational phenomenology, data analysis, and computational theory."

Salvesen's thesis will focus on the properties of accretion disks in black-hole x-ray binary systems. A major project is to determine whether the observed properties of disks can be used to infer the spin of the central black hole. This is an important topic for understanding how stellar-mass black holes form and evolve. His work promises not only to shed new light on this topic, but also lead to new insights into the physics of accretion disks.

"Greg is amazingly productive and focused for a graduate student," Begelman says. "He has already published five papers in *The Astrophysical Journal* and the *Monthly Notices of the Royal Astronomical Society*."

THREE YOUNG JILA SCIENTISTS GARNER POSTER AWARDS

Two JILA graduate students and one undergraduate student were recognized with awards for their posters and presentations at the recent Boulder Laboratories Postdoctoral Poster Symposium, held at NIST Boulder (325 Broadway) on Wednesday, June 18, 2014. The Outstanding Presentation Award is a special recognition for selected poster presenters at the Boulder Laboratories Postdoctoral Poster Symposium. This recognition was conferred by senior scientists who circulated through the poster session and noted

outstanding quality in both preparation of a poster and its oral presentation.

Undergraduate student Andrew Barentine was recognized with an Outstanding Presentation Award for his presentation "Non-Equilibrium Steady State Oscillations in Isotropic Traps," with co-authors Dan Lobser, Heather Lewandowski, and Eric Cornell.

Graduate student Craig Benko was recognized with an Outstanding Presentation Award for his presentation "Phase Coherent Extreme Ultraviolet Radiation," with co-authors Craig Benko, Thomas K. Allison, Arman Cingöz, Linqiang Hua, François Labaye, Dylan C. Yost, and Jun Ye.

Graduate student Matt Norcia was recognized with an Outstanding Presentation Award for his presentation "Reduced Back Action for Improved Spin Squeezing," with co-authors Justin Bohnet, Kevin Cox, Joshua Weiner, Zilong Chen, and James K. Thompson.

ROB WALDER WINS BEST POSTER AWARD

NRC post-doc Rob Walder has won a "Best Poster" award at the Single Molecule Approaches to Biology Gordon Research Conference in Italy for his poster entitled "An Ultrastable Platform for Single Molecule Measurements: Sub-Nanometer Drift in 3D for Hours." Walder works with the Perkins group.

ADAM KAUFMAN AND KEVIN COX RECEIVE POSTER PRIZES AT ICAP

Graduate students Kevin Cox (Thompson Lab) and Adam Kaufman (Regal Lab) received "ICAP 2014 Best Poster Presentation" awards at this year's International Conference on Atomic Physics in Washington DC. Adam's poster was entitled: "Atomic Hong-Ou-Mandel effect in tunnel-coupled optical tweezers." Kevin's poster was entitled: "Synchronization in Superradiant Lasers."

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 three John D. and Catherine T. MacArthur Fellows, Margaret Murnane, Deborah Jin, and Ana Maria Rey. JILA's CU members hold faculty appointments in the Departments of Physics; Astrophysical and Planetary Sciences; Chemistry and Biochemistry; and Molecular, Cellular, and Developmental Biology as well as in the School of Engineering. NIST's Quantum Physics Division members hold adjunct faculty appointments at CU in the same departments.

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 seven broad categories: Astrophysics, Atomic & Molecular physics, Biophysics, Chemical physics, Laser Physics, Nanoscience, Precision Measurement, and Quantum Information.

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