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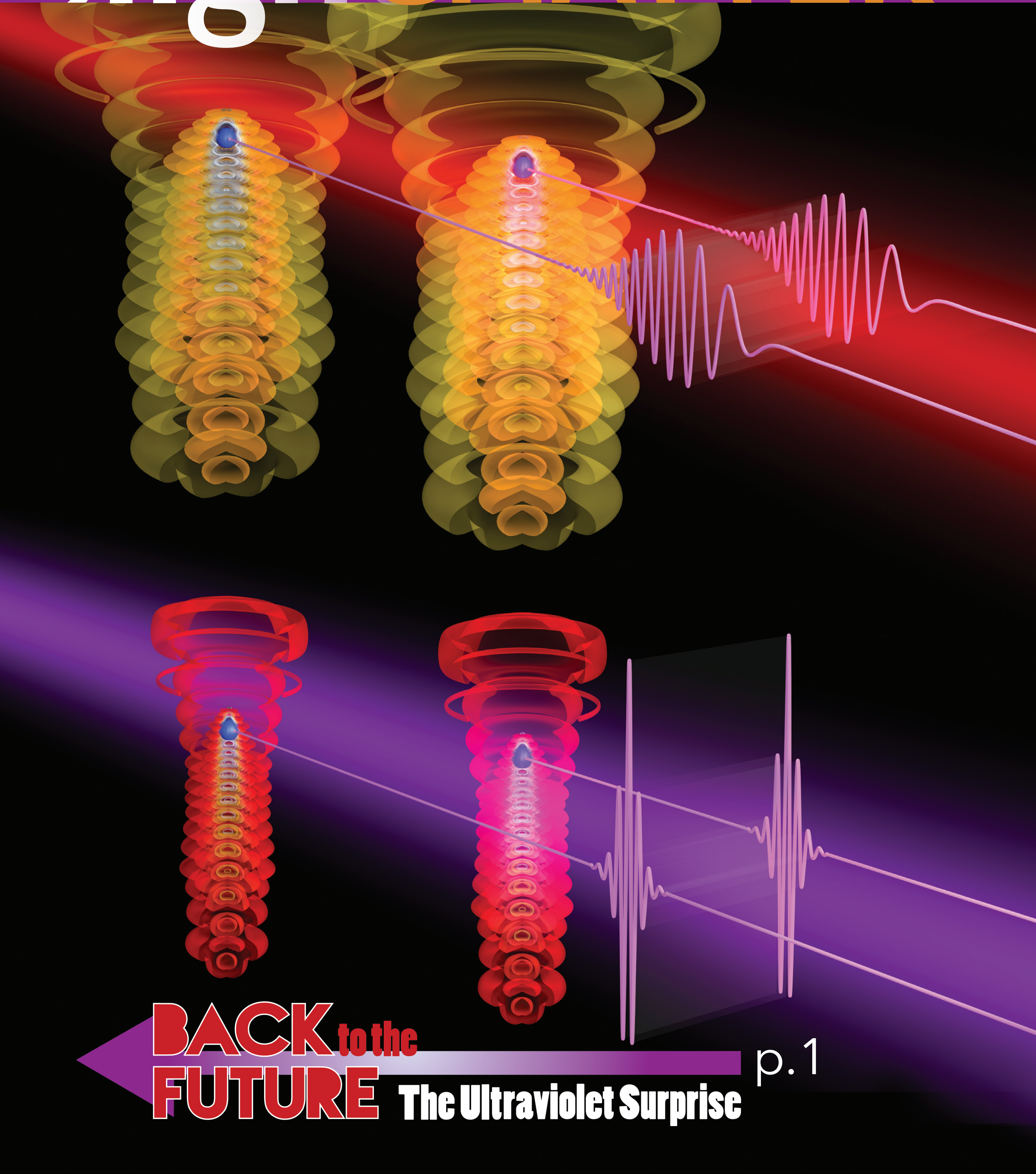
JILA light&MATTER



BACK to the FUTURE The Ultraviolet Surprise

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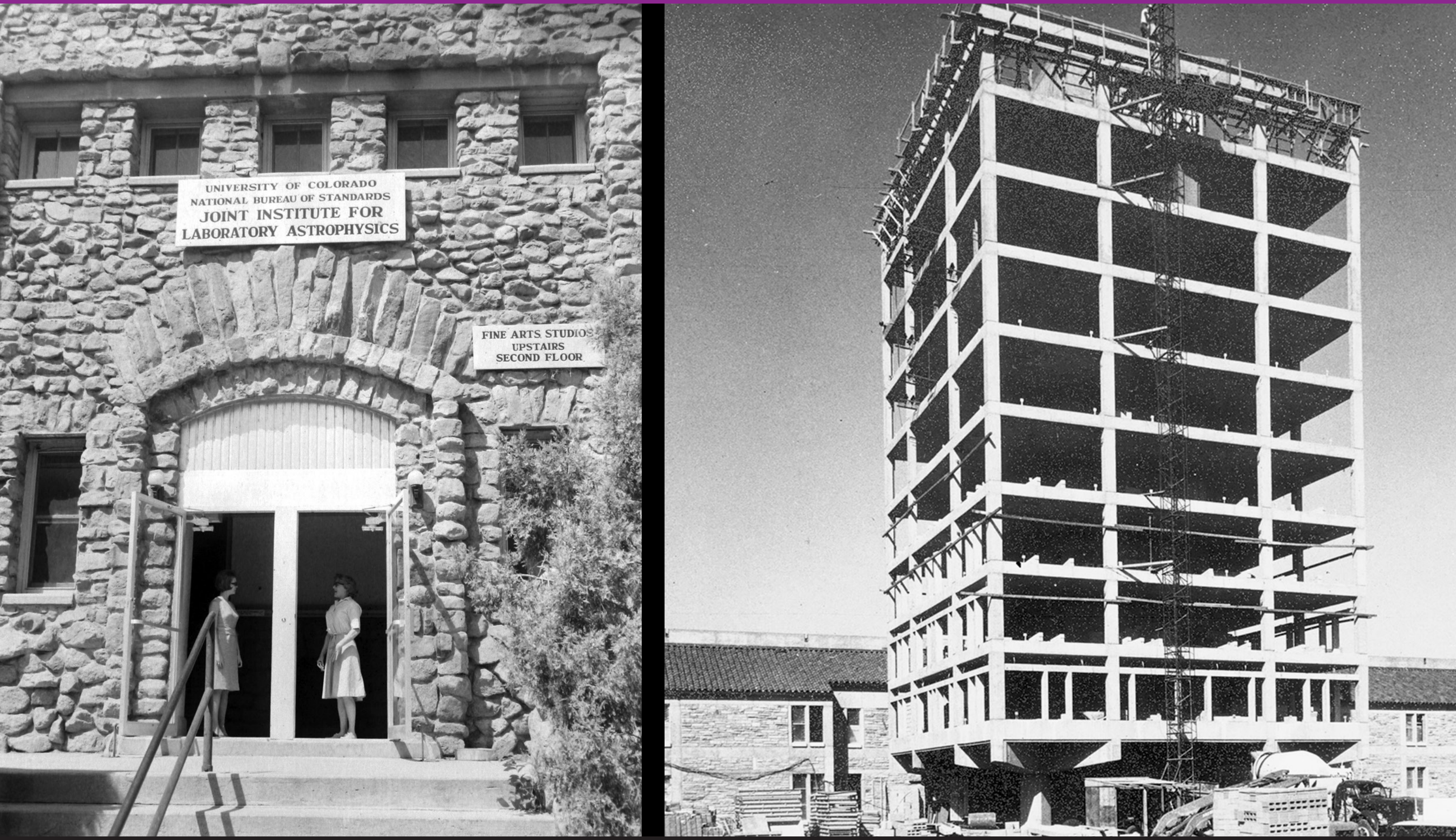

Left: Close-up of the entrance to the old State Armory Building, JILA's first home on the University of Colorado campus, in the early 1960s. Right: The 10-story JILA tower under construction, in 1966, in front of the recently completed laboratory wing. Credit: JILA.

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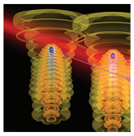
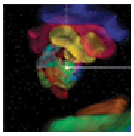
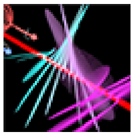
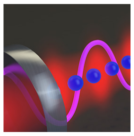



Features

BACK to the FUTURE

The Ultraviolet Surprise

Imagine laser-like x-ray beams that can "see" through materials—all the way into the heart of atoms. Or, envision an exquisitely controlled four-dimensional x-ray microscope that can capture electron motions or watch chemical reactions as they happen. Such exquisite imaging may soon be possible with laser-like x-rays produced on a laboratory optical table. These possibilities have opened up because of new research from the Kapteyn/Murnane group.

For example, one important part of a microscope is the light used to illuminate the sample. Exciting recent experiments by Assistant Research Professor Tenio Popmintchev, the K/M group, and colleagues from around the world used an ultraviolet (UV) laser and converted its light to much shorter wavelengths via high-harmonic generation (HHG). The researchers successfully generated a comb of bright extreme UV and soft x-ray harmonics that are ideal for imaging the nanoworld. This discovery complements the rainbows of harmonics that can be produced using mid-infrared lasers that this team demonstrated in 2012. This stunning accomplishment, until recently thought to be impossible, was reported online in *Science* in November 2015.

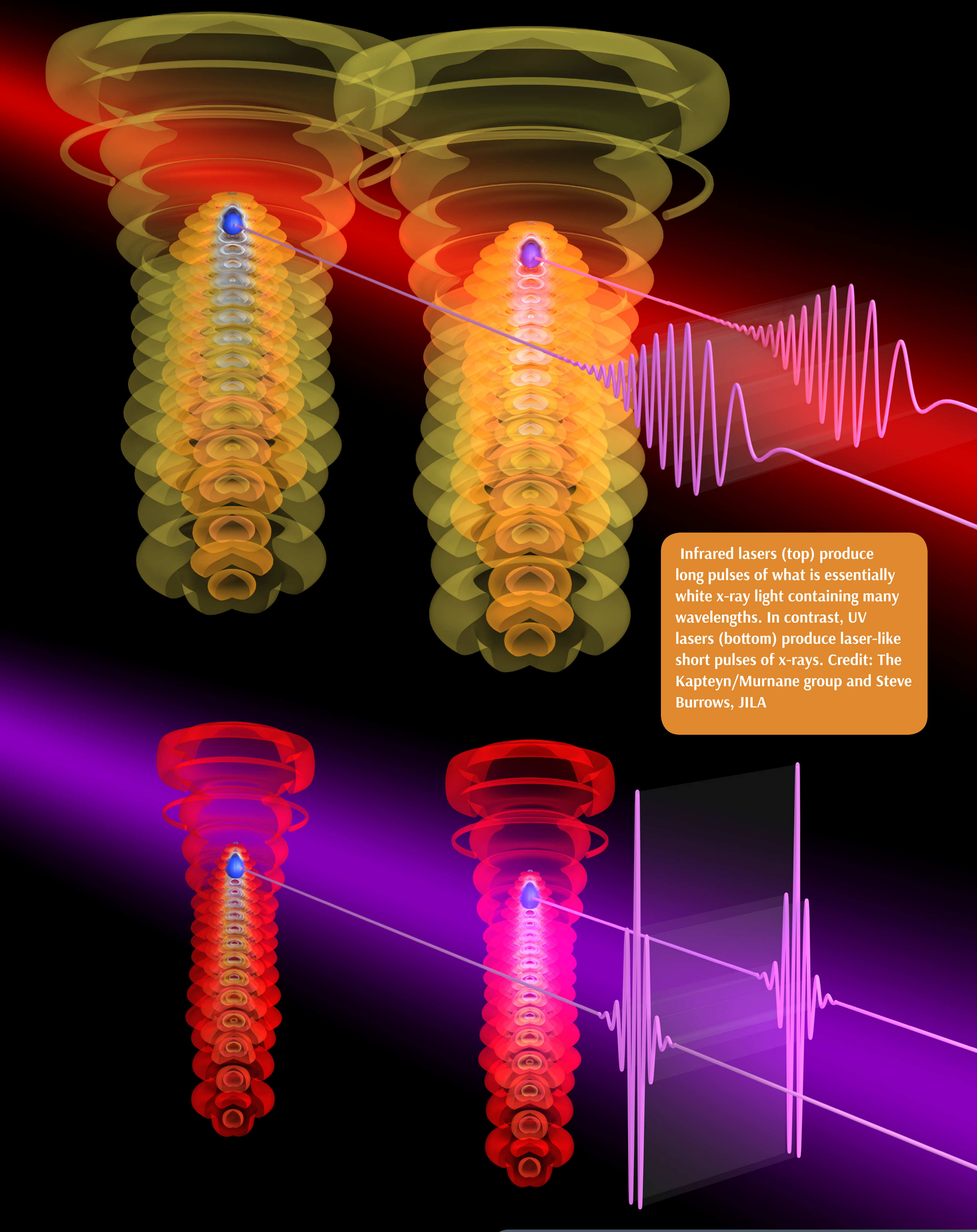
The JILA researchers contributing to this breakthrough include Tenio Popmintchev, graduate students Dimitar Popmintchev and Christopher Mancuso, former research associates Carlos Hernández-García, Franklin Dollar, and Ming-Chang Chen, former student assistant Amelia Hankla, and Fellows Agnieszka Jaron-Becker, Andreas Becker, Margaret Murnane, and Henry Kapteyn. The JILA team collaborated with colleagues from the University of Salamanca (Spain), National Tsing Hua University (Taiwan), Cornell University, Temple University, and Lawrence Livermore National Laboratory.

For Tenio Popmintchev and the K/M group, the success of their new HHG experiment was a *Back to the Future* moment. The process of high harmonic generation in gases was discovered using UV lasers nearly 28 years ago. But, because scientists at that time didn't fully understand how to make this process efficient, attention turned to using longer-wavelength lasers for HHG. In fact, for many years, most scientists believed that producing soft x-ray harmonics with UV lasers would be impossible. As it turned out, it was not impossible. Instead, it was the ultraviolet surprise.

"In the very first experiments, they had driving UV lasers with much longer pulse durations," Tenio Popmintchev explained. "Now, as the laser technology has advanced, we can make very high-energy driving lasers with pulse durations that are an order of magnitude shorter. This is what it takes to produce x-ray harmonics in this regime." Knowing this, Tenio Popmintchev was able to build the right UV laser for the job.

Once the new laser was operational, the researchers discovered that it extended the reach of HHG well beyond what they expected. And, the process occurred in a very different way than with a mid-IR driving laser. The conversion of mid-IR laser light into x-ray light requires gently ionized atoms to add the radiation from all atoms constructively. In contrast, the conversion of UV laser light takes place in a cloud of multiply charged ions in a high-density plasma. Until this experiment, the researchers thought that a plasma would destroy the HHG efficiency by causing the HHG waves to interfere destructively.

(continued on page 3)



Infrared lasers (top) produce long pulses of what is essentially white x-ray light containing many wavelengths. In contrast, UV lasers (bottom) produce laser-like short pulses of x-rays. Credit: The Kapteyn/Murnane group and Steve Burrows, JILA *(continued from page 1)* Fortunately, in this new regime, the researchers were able to maximize the HHG emission from each ion and efficiently combine the HHG waves from many ions. In the HHG process, the laser rips an electron from an ion, then accelerates it away before driving the electron back to the same ion from which it originated. The brightness of the x-rays emitted depends on how likely it is that the electron recombines with the ion. For a UV laser, the electron spends less time away from the ion, so the x-rays that are created are brighter.

"If you use mid-infrared (IR) lasers, then you get a coherent supercontinuum rainbow of x-ray light," said Margaret Murnane. "The very nice thing with UV lasers is that you get very narrow peaks. So this is yet another example of a powerful and beautiful ability to manipulate x-ray light using laser light."

With mid-IR lasers, for example, the supercontinuum is like white light in the x-ray region. The supercontiuum is expected to work well for watching chemical reactions, where a lot is going on. In contrast, a UV laser driving HHG produces a comb-like band of nano-linewidth harmonics. These harmonics are ideal for imaging tiny objects such as atoms, molecules, and nanomaterials.

The Kapteyn/Murnane group is currently using its UV laser-generated harmonics to investigate nanomaterials. Soon, the researchers hope to produce even shorter-wavelength light that will allow them to resolve biological materials such as DNA, RNA, proteins, and viruses. ✺

Dimitar Popmintchev, Carlos Hernández-García, Franklin Dollar, Christopher Mancuso, Jose A. Pérez-Hernández, Ming-Chang Chen, Amelia Hankla, Xiaohui Gao, Bonggu Shim, Alexander Gaeta, Maryam Tarazkar, Dmitri Romanov, Robert Levis, Jim A. Gaffney, Mark Foord, Stephen B. Libby, Agnieszka Jaroń-Becker, Andreas Becker, Luis Plaja, Margaret M. Murnane, Henry C. Kapteyn, Tenio Popmintchev, *Science* **350**, 1225–1231 (2015).

JILA's Scientific Communications Office recently set up a photo studio in the east portion of room S211. Faculty and staff who need passport photos, "head shots" for publicity, or other photographic needs now have a convenient place to go. Contact Steve Burrows (steven.burrows@jila.colorado.edu) to set up an appointment.

Matt Grau, of the Cornell group, was the first client to be photographed by Steven Burrows for a new passport photo. Credit: Julie Phillips, JILA.

IN THE NEWS

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

THOMAS PERKINS: ATOMIC FORCE MICROSCOPY MEASURES PROPERTIES OF PROTEINS AND PROTEIN FOLDING (SPIE VIDEO)

Thomas Perkins was featured in a SPIE video discussing his Atomic Force Microscopy instrument that is used for measuring the properties of proteins and protein folding. The approximately 8 minute video can be viewed at: https://goo.gl/9piR96

MATT NORCIA WINS JILA SCIENTIFIC ACHIEVEMENT AWARD

Graduate Student Matt Norcia (Thompson group) received a JILA Scientific Achievement Award on February 18. The announcement took place during a special snack time in the Sunrise Room of the JILA Tower.

Norcia was cited for building a strontium cavity-QED experiment from scratch. Norcia's advisor, James Thompson, nominated him for the prestigious award. Thompson noted that Norcia's experiment had accomplished important research goals for the group. Norcia's work is expected to result in publications in *Physical Review A*, *Physical Review X*, and *Science*.

"I believe that Matt is one of the best experimentalists I have ever worked with here at JILA and at MIT," Thompson said in his nomination letter.

Congratulations Matt!

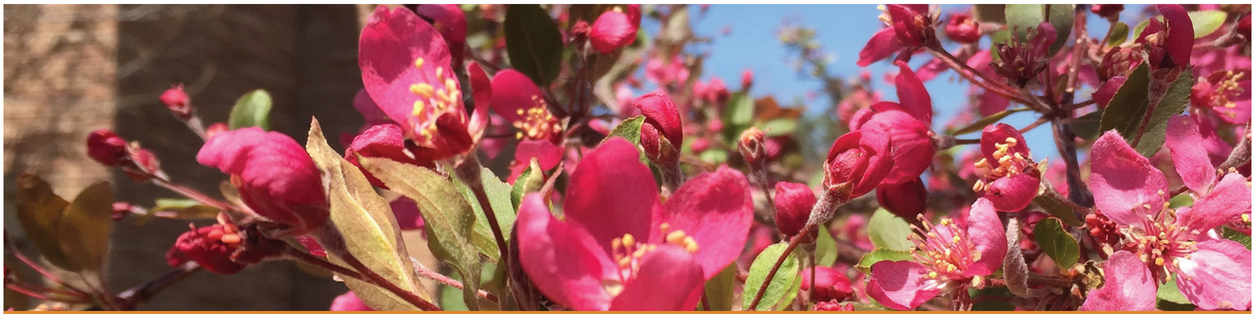
JILA'S INSTRUMENT SHOP IS FEATURED IN THE COLORADAN MAGAZINE

When James Bond needs a new gizmo to carry out acts of spymaster derring-do, he heads straight for Q. CU scientists have a gadget team of their own.

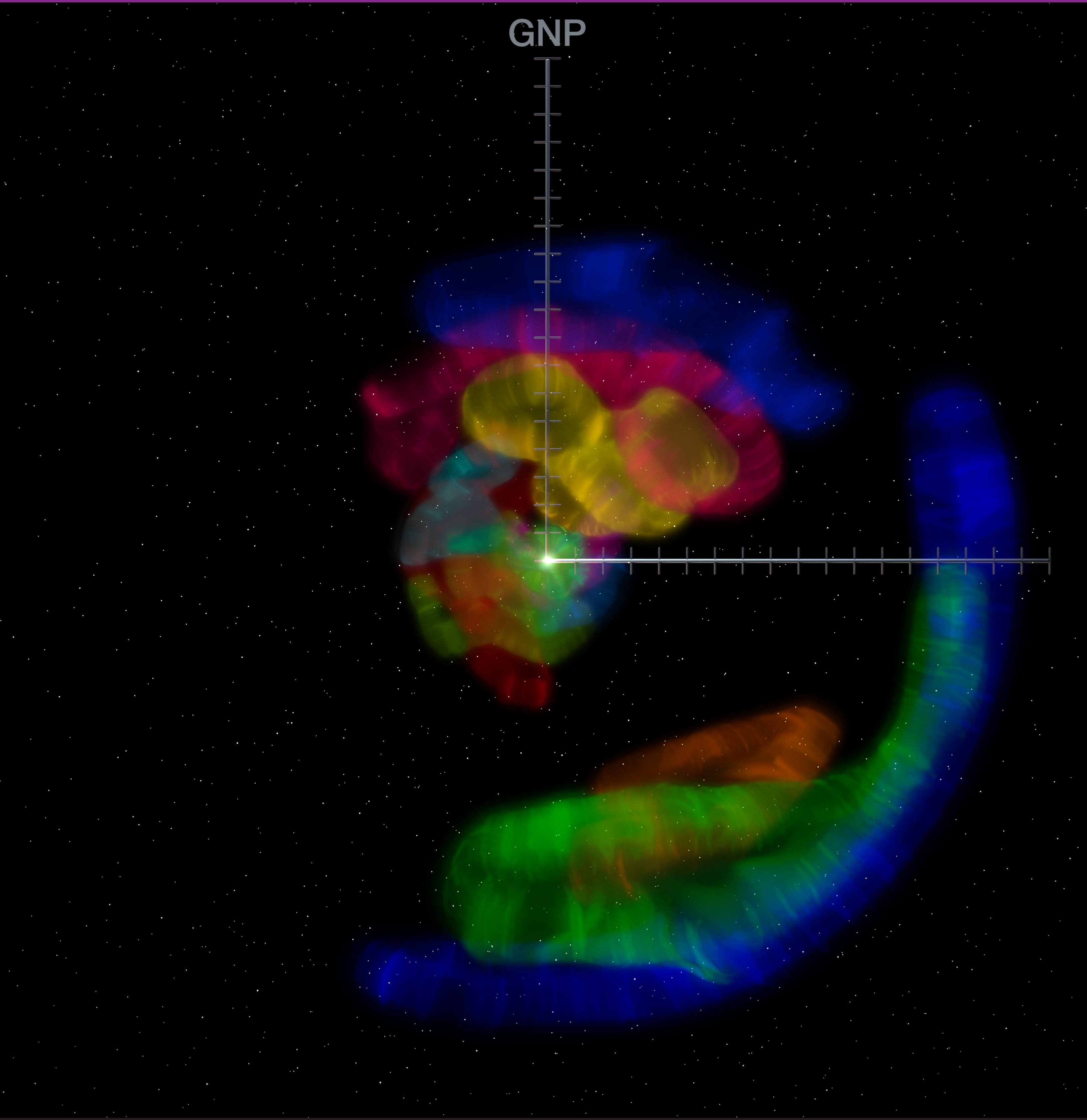
To the physicists and chemists of CU-Boulder, Hans Green (CU Alumni, History 1995) and the JILA team say this: If you conceive it, we will build it.

James Bond has Q, the irascible tinkerer extraordinaire of the British Secret Service; CU-Boulder scientists have an entire squad of gadgetry wizards at the JILA Instrument Shop, which designs and manufactures custom equipment for work at the leading edge of physical science—stuff researchers need for their experiments but can't buy anywhere.

Read the entire article at *Coloradan Magazine*, CU Boulder's alumni magazine, here: http://goo.gl/Nr3jfb



Crabapple blossoms on the CU campus in April of 2016.



Fifteen clouds of warm gas surrounding the solar system, as modeled by Seth Redfield and Jeff Linsky. New data from the Hubble Space Telescope better supports this model than a competing model that posits just a single large cloud of gas. Credit: S. Redfield, J. Linsky, and Steve Burrows, JILA

We've Looked at Clouds from Both Sides Now

–after Joni Mitchell

In 2008, Fellow Jeff Linsky and his colleague Seth Redfield of Wesleyan University used spectral information gathered by the Hubble Space Telescope to figure out that the solar system is surrounded by 15 nearby clouds of warm gas, all within 50 light years of the Sun. In 2014, Cécile Gry of Aix-Marseille Université (France) and Edward Jenkins of Princeton University Observatory analyzed the same data, but came up with a much simpler picture of the local interstellar medium, or LISM. These researchers suggested that rather than comprising 15 different clouds, the LISM is made of a single continuous cloud that surrounds the Sun.

When the second model was proposed, the two groups of astrophysicists did what scientists do best. They began citing additional evidence supporting their respective models, which were both consistent with the same data set. One argument made by Gry and Jenkins was that if there are 15 separate clouds, then there should be holes among the clouds, but no such holes have been found. Linsky and Redfield countered with an analysis showing that the odds of finding even a single hole were much less than one-tenth of 1%.

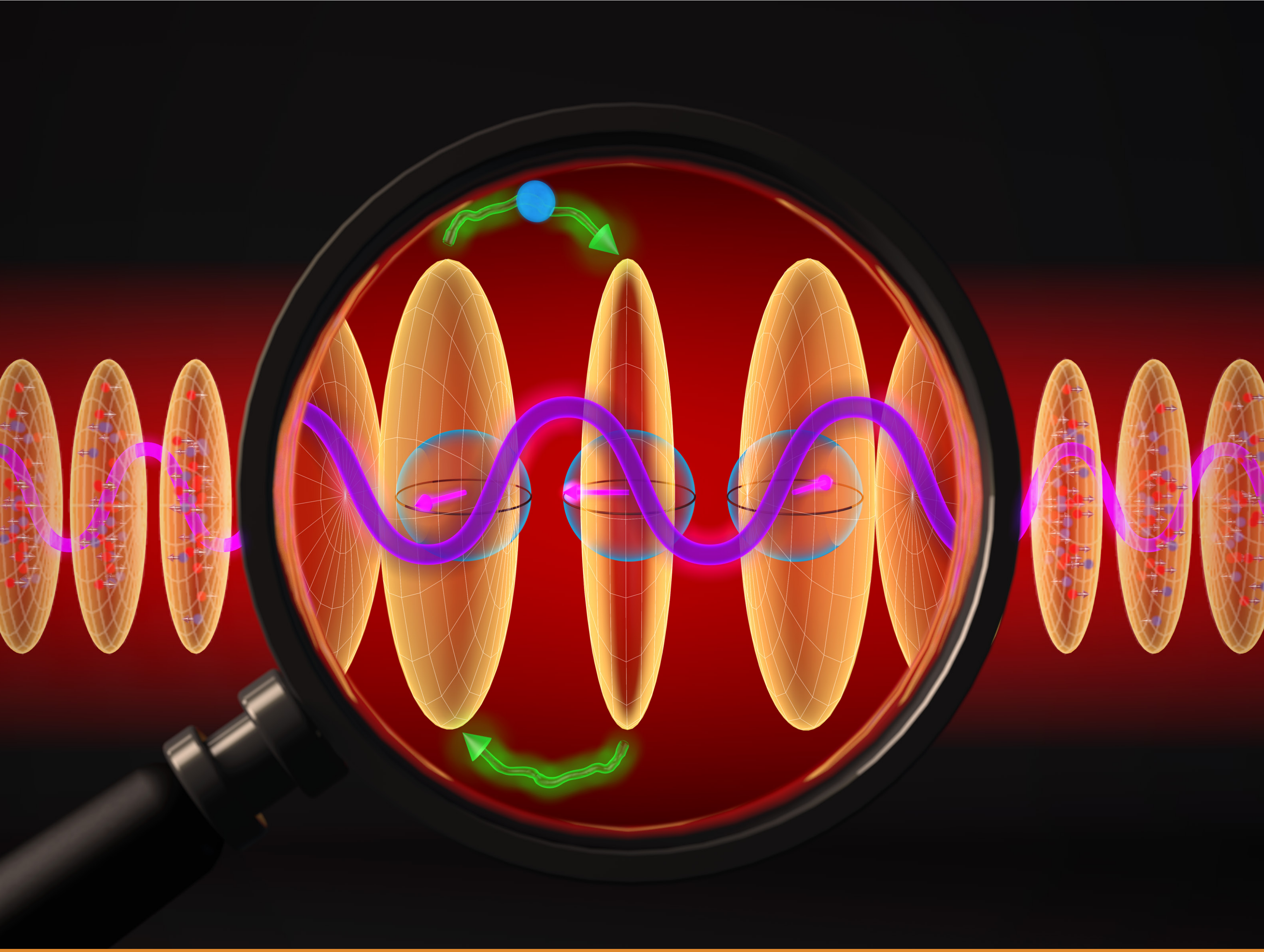
For their part, Linsky and Redfield offered three reasons in support of their theory. First, they pointed out that the speed and direction of the flow of gas is different for each one of their 15 clouds. So, they asked Gry and Jenkins to propose a mechanism to explain how a single continuous cloud could exhibit so many changes in speed and direction. Second, many of the 15 clouds appear to be quite long and thin because they are shaped (as predicted) by strong magnetic fields near the Sun. Finally, the 15-cloud model explains why quasars twinkle at radio-wave frequencies. Twinkling results from the interaction of Earth's changing position as it orbits around the Sun with the irregular shape of the local interstellar clouds found in the direction of twinkling quasars. Since only quasars in the lines of sight through cloud boundaries twinkle, individual LISM clouds must periodically lie in between the twinkling quasars and Earth.

However, a more quantitative test of the two models came in 2014. The Hubble Space Telescope obtained new, high-resolution spectra of stars shining through the LISM. When the researchers looked at the new data, Linsky and Redfield's 15-cloud model was significantly better at predicting specific stellar spectral observations than the single-cloud model of Gry and Jenkins.

The new observations also underscored the idea that there are still many questions to be answered about the structure of the LISM. For instance, even though they are difficult to detect, there should be identifiable holes between 15 separate clouds. Linsky and Redfield's theory would be even more strongly supported if such holes were discovered and characterized.

Another benefit would be that science's understanding of our corner of the Universe would be enhanced. And, the better scientists understand the properties and evolution of the interstellar medium close to home, the better chance they have of understanding it across wide swaths of the Universe. ✺

Seth Redfield and Jeffrey L. Linsky, *The Astrophysical Journal* **812**, 125 (2015).



Inside an optical lattice clock, a probing laser rotates the atoms' spin (arrows in blue spheres) differently depending on their position. When atoms tunnel (green arrows) between different pancake-like layers, this position-dependent rotation acts like spin-orbit coupling and moves the atoms in a circular path, mimicking the motion of electrons in a magnetic field. Credit: The Rey and Ye groups and Steve Burrows, JILA

CREATIVE ADVENTURES IN COUPLING

New theory furthers goal of making cold atoms behave as if they were electrons

The Rey and Ye groups are in the midst of an extended collaboration on using the Ye group's strontium (Sr) lattice clock for studies of spin-orbit coupling in pancake-like layers of cold Sr atoms. Spin-orbit coupling means an atom's motion is correlated with its spin. It occurs in everyday materials when negatively charged electrons move in response to electromagnetic fields inside a crystal. By making cold neutral atoms behave as charged particles, it will be possible to better understand the behavior of electrons in solids, something that is essential for developing improved quantum materials and technologies such as spintronic devices, which use spins rather than electric charge to carry information. Additionally, an in-depth understanding of spin-orbit coupling is necessary for advancing our fundamental understanding of modern quantum science.

A new theory study by the Rey group has outlined the many advantages of the Ye group's Sr-lattice clock for experimental spin-orbit-coupling studies. The clock consists of individual two-dimensional "pancake" layers of about 10 to 100 identical Sr atoms. However, the atoms in different pancakes are not identical because the clock laser "talks" to them differently. After "talking" with the laser, pancakes of identical atoms differ from one another in phase. As a result, if individual Sr atoms tunnel from one layer to another, they can readily be identified as "different" and will collide as nonidentical quantum particles. Any frequency differences associated with their energy and motional states can be detected with the exquisitely stable clock laser. However, quantum tunneling doesn't normally happen in the clock because the layers of atoms are held inside a deep lattice.

With this understanding in mind, the theoretical study laid out an approach for using the Sr-lattice clock to better understand spin-orbit coupling. First, by decreasing the lattice depth, it would be possible for atoms to tunnel between the layers. At the same time, the clock laser would be able to drive the atoms between different electronic states. Together, these two processes would cause the atoms to move in a circular pattern, emulating the circular motion of charged electrons in a magnetic field.

Second, the theorists predicted that spectroscopy performed with the clock laser would be able to resolve the momentum of individual atoms in specific layers and "see" the atoms collide when they move between layers. Third, they proposed a way to control atomic transport, including predicting a way to modify this process by controlling the atomic collisions. Finally, they showed that these experimental investigations would be possible at current operating temperatures of one of the Sr-lattice clocks in the Ye labs.

The researchers responsible for this intriguing analysis included research associate Michael Wall, graduate student Andrew Koller, former graduate student Shuming Li, former research associate Xibo Zhang (now at Peking University in Beijing), former visiting fellow Nigel Cooper (now at Cavendish Laboratory in Cambridge, UK), as well as Fellows Jun Ye and Ana Maria Rey.

The theorists are excited about upcoming tests of their ideas with the Ye group's Sr-lattice clock. Because of the clock's ultrastable lasers, the experimentalists will be able to observe the Sr atoms for a very long time—long enough to observe the combined effects of atomic interactions and spin-orbit coupling. In the process, both theorists and experimentalists are looking forward to discovering new and as-yet-unpredicted aspects of spin-orbit coupling. At the same time, they hope to better understand how to use cold atoms as electron analogs. ✺

Michael L. Wall, Andrew P. Koller, Shuming Li, Xibo Zhang, Nigel R. Cooper, Jun Ye, and Ana Maria Rey, *Physical Review Letters* **116**, 035301 (2016).

A Walk Through Time

ACROSS

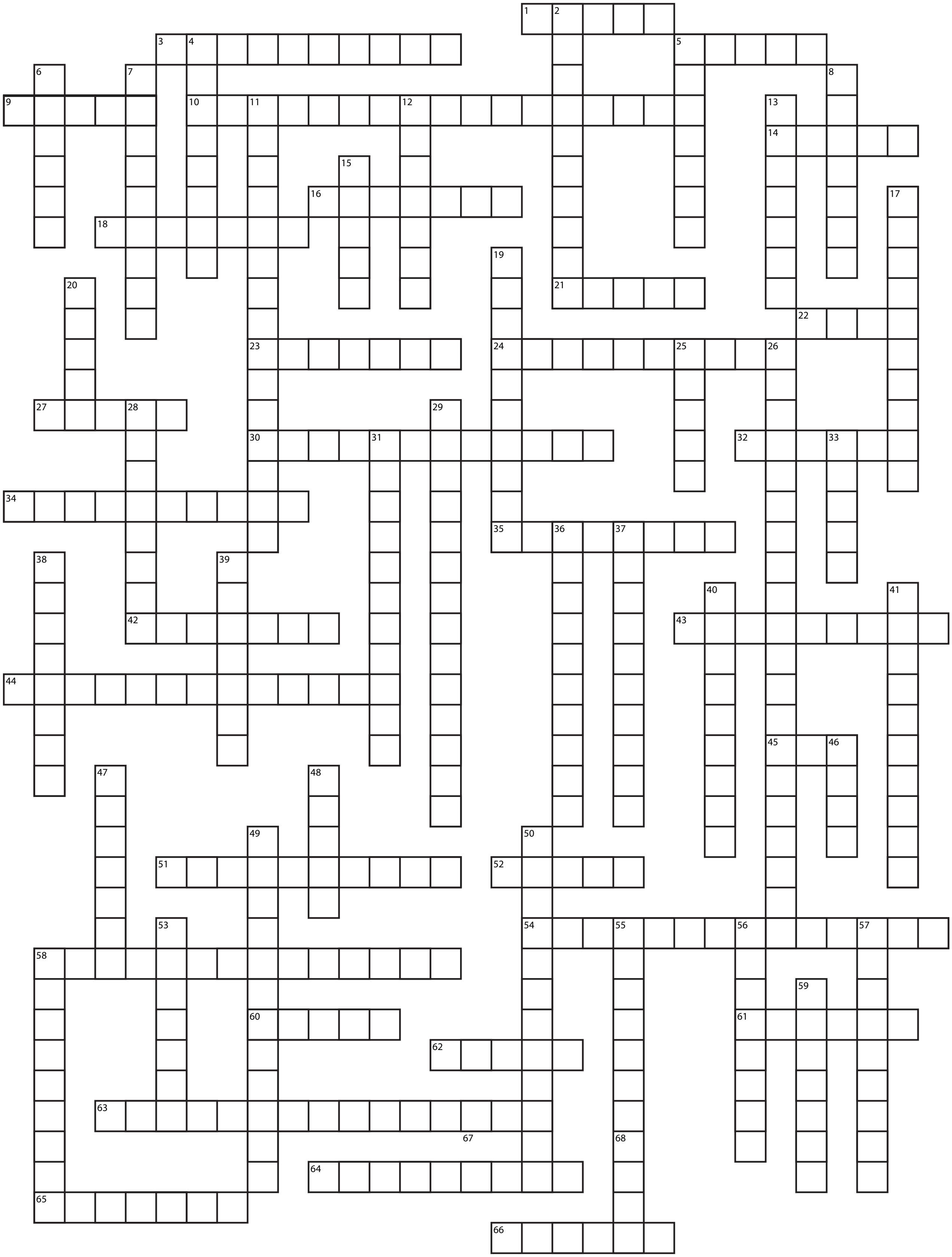
1. With 61 across, helped explain theory of superconductivity.
3. Early 20th century revolutionary theories of special and general ____________________.
5. Developed first nuclear reactor and made major contributions to quantum theory.
9. Serbian physicist and inventor known for inventing an AC induction motor.
10. Practice of studying nature prior to the 19th century.
14. First to prove the existence of electromagnetic waves.
16. Formulated 1785 law describing interaction between electrically charged particles.
18. Italian mathemetician, astronomer, and physicist responsible for the birth of modern science.
21. Where 2 down lived in Greece.
22. First to theoretically explain nuclear physics.
24. Mapped the motion of stars and planets & predicted eclipses more than 100 years before the birth of Christ.
27. Described the behavior of fermions and predicted existence of antimatter.
30. Accurately estimated Earth's circumfrence in 240 BCE.
32. Discovered the laws of planetary motion.
34. Developed theory of atomism.
35. Where 19 down lived.
42. Basra mathematician considered the father of modern optics.
45. German physicist and mathematician who discovered current is proportional to voltage and inversely proportional to resistance in an electric circuit.
51. Formulated the first law of thermodynamics.
52. Renaissance physicist who clarified the concepts of pressure and vacuum.
54. Laid the foundation for classical mechanics, built the first (41, 57 down), invented 56 down, and observed that a prism splits white light into the colors of the rainbow.
60. 2013 Nobel Laureate who predicted his namesake 62 across.
61. Leon's pairs of electrons or other fermions bound together at low temperatures (with 1 across).
62. Particle that can occupy the same states as others of its kind.
63. Swiss physicist known for his principle explaining fluid flow.

DOWN

2. Greek philosopher who proposed heliocentric model of solar system.
4. Physicist responsible for 3 across.
6. He discovered the splitting of a spectral line in the presence of a magnetic field, an effect now named after him.
8. Showed how a changing magnetic field can be used to generate electric current.
11. "Father of Science" who refused to accept supernatural explanations for natural phenomena.
12. Early physicist who lived during Roman times and authored scientific treatises that influenced Islamic and European science.
13. The J.J. who won 1906 Nobel Prize for the discovery of the electron.
15. Built the first electric battery and lent his name to the unit of electrical potential.
17. Famous for uncertainty.
19. Greatest mathematician of antiquity (and one of the greatest of all times) who laid foundation of hydrostatics and statics.
20. Quantum physics pioneer famous for exclusionary thinking.
25. Last name of discoverers of radioactivity.
26. Advancement of scientific progress during the 16th and 17th centuries.
28. Medieval polymath from Bukhara who contributed to physics, optics, and medicine.
29. English physicist and cosmologist who predicted that black holes emit radiation.
31. Persian scientist who calculated length of the solar year within a fraction of a second of modern calculations.
33. 1964 invention without which most JILA research would likely be impossible.
36. Father of nuclear physics who named alpha and beta radiation.
37. Polish astronomer who proposed heliocentric model of the solar system in 1543.
38. Name for an atom described as small, positively-charged nucleus surrounded by electrons that travel around it in circular orbits.
39. With 40 down, first half of the name of new 20th century theory that solved the *ultraviolet catastrophe*.

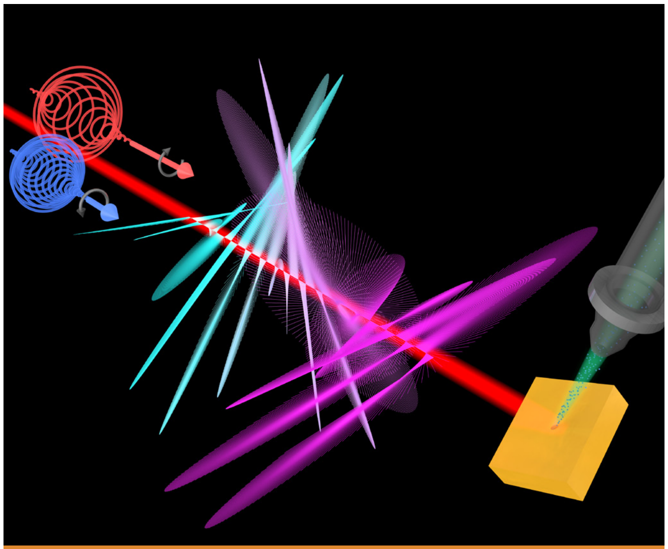
Crossword clues continued on page 12

Be the first one to solve the puzzle and win a $25 gift card. Just bring your completed puzzle to Kristin Conrad (S264) or Julie Phillips (S209). Congratulations to Philipp Schmid of the Lewandowski group, winner of the puzzle contest for the 2016 winter issue of JILA Light & Matter.



RECONSTRUCTION

Photoelectrons reveal the most complex light field to date



By simultaneously illuminating a copper surface with circularly polarized extreme ultraviolet (EUV) light and an infrared laser beam that is perfectly synchronized with the EUV light, the Kapteyn-Murnane group was able to reconstruct the most complex light field to date. In these circularly polarized EUV bursts, the electric field oscillates and the polarization changes on attosecond time scales. Credit: The Kapteyn/ Murnane group and Steve Burrows, JILA.

Cong Chen and his colleagues in the Kapteyn/ Murnane group have generated one of the most complex coherent light fields ever produced using attosecond (10^{-18} s) pulses of circularly polarized extreme ultraviolet (EUV) light. (The circularly polarized EUV light is shown as a rotating blue sphere on the left of the picture.The complex coherent light field is illustrated with the teal, lilac, and purple structures along the driving laser beam, shown as wide red line).

The amazing thing about this work is that the researchers accomplished it without lenses, mirrors, or other devices used to measure visible light. Because optical devices don't work with EUV light, the team had come up with a unique way to reconstruct the new, complex light field: investigating the properties of photoelectrons generated from a copper surface by the extremely complex light field. Thus, in this seminal work, the team pioneered the generation of extremely complex light fields and developed a novel way to accurately measure those fields.

The researchers were first able to make circularly polarized EUV bursts using high-harmonic generation (HHG). Next, they came up with a clever way of transferring the information about the circularly rotating EUV light onto photoelectrons, which can be measured. For this, they irradiated a copper surface (yellow) with the circularly polarized EUV bursts, a process that kicked out photoelectrons (green) from the surface. If the surface was also illuminated with an infrared laser pulse (red, left) at the same time, the laser field "wiggled" the photoelectrons liberated by the EUV light.

"By looking at those wiggling electrons, we observed that the electrons liberated by slightly different bursts of EUV light come out at slightly different times," Margaret Murnane said. "And if we move the EUV and laser light waves by a very small amount, by less than a wavelength of visible light, we can rotate the direction of the circular EUV field—just like rotating the arms in a clock. This allows us to collect photoelectrons as we rotate the EUV polarization, and know everything about the most complex coherent light pulse generated to date!"

The rotation of the circular EUV field allowed the researchers to determine that circularly polarized EUV light is actually a superposition of three linear pulses offset from each other by 120 degrees. This superposition formed the new state of circularly polarized light!

With this knowledge, the researchers were able to reconstruct a complete three-dimensional map of the EUV burst from the tiny shifts of the wiggling electrons. Two factors were critical to making the map of an incredibly complicated EUV light field: (1) the photoelectrons coming from the copper surface were sensitive to the polarization of the EUV light, and (2) the researchers were able to rotate the circularly polarized EUV light as it was created.

The researchers responsible for this illuminating feat include graduate students Chen, Dmitriy Zusin, and Christian Gentry, research associates Zhensheng Tao, Ronny Knut, and Patrik Grychtol, former research associate Piotr Matyba, former graduate student Tory Carr, and Fellows Agnieszka Jaron-Becker, Andreas Becker, Henry Kapteyn, and Margaret Murnane as well as their colleagues from the Universidad de Salamanca (Spain) and Technion (Israel).

The reconstruction of circularly polarized EUV light opens the door to gaining a deeper understanding of atoms, and molecules whose mirror images cannot be superimposed on each other, and magnetic materials. ✺

C. Chen, Z. Tao, C. Hernández-García, P. Matyba, A. Carr, R. Knut, O. Kfir, D. Zuzin, C. Gentry, P. Grychtol, O. Cohen, L. Plaja, A. Becker, A. Jaron-Becker, H. Kapteyn, M. Murnane, *Science Advances* **2**, e1501333–e1501333 (2016).

Crossword Clues, continued from page 9

ACROSS

64. Father of statistical mechanics, he also developed the kinetic theory of gases.
65. Dutch physicist, who with 6 down, discovered and explained the "6 down" effect.
66. Founder of electrodynamics and namesake of the unit of electric current.

DOWN

40. With 39 down, second half of the name of new 20th century theory that solved the *ultraviolet catastrophe*.
41. With 57 down, first half of name of an optical device using one or more curved mirrors to reflect light and form an image.
46. Studied shock waves and distribution of airflow; ratio of flow velocity past a boundary to speed of sound is named after him.
47. Produced and detected X-rays in 1895 for which he earned the first Nobel Prize in Physics in 1901.
48. Discovered heat is a form of energy and found the relationship between current through resistance and the heat dissipated, a law now name after him.
49. First and last name of physicist who predicted the orbit of the comet named after him.
50. The three things that 54 across figured out that every first year physics student learns.
53. Won a Nobel Prize in 1956 for the invention of the transistor and another in 1972 for the fundamental theory of superconductivity.
55. Austrian physicist known for work in quantum field theory, which was the basis for wave mechanics and his world-famous eponymous equation.
56. Mathematical study of change developed (in part) by 54 across.
57. With 41 down, second half of name of an optical device using one or more curved mirrors to reflect light and form an image.
58. Discovered radioactivity along with the Curies.
59. Described how observed frequencies of light and sound are affected by the relative motion of the source and detector.

TALKING ATOMS & COLLECTIVE LASER SUPERCOOLING

New theory predicts "collective" cooling of nanoparticles to near absolute zero

Move over, single-atom laser cooling! The Holland theory group has just come up with a stunning idea for a new kind of laser cooling for use with ensembles of atoms that all "talk" to each other. In other words, the theory looks at laser cooling not from the perspective of cooling a single atom, but rather from the perspective of many atoms working together to rapidly cool themselves to a miniscule fraction of a degree above absolute zero. And, this new theory (which hasn't been tried out yet in the lab) would not only cool atom ensembles to record-breaking low temperatures, but also cool them down even faster than ever before!

The proposed cooling method is related to the operation of a superradiant laser. In a superradiant laser, the collective effects of all the atoms in the laser talking to each other determines the narrow linewidth, or frequency stability, of the laser light. With cooling, the collective effects of all the atoms talking to each other means it may be feasible to get a cloud of atoms even colder under superradiant conditions than physicists thought possible.

The theorists responsible for this tantalizing new idea include graduate student Minghui Xu, retired Fellow Jinx Cooper, and Fellow Murray Holland, as well as colleagues from the Universität des Saarlandes (Germany).

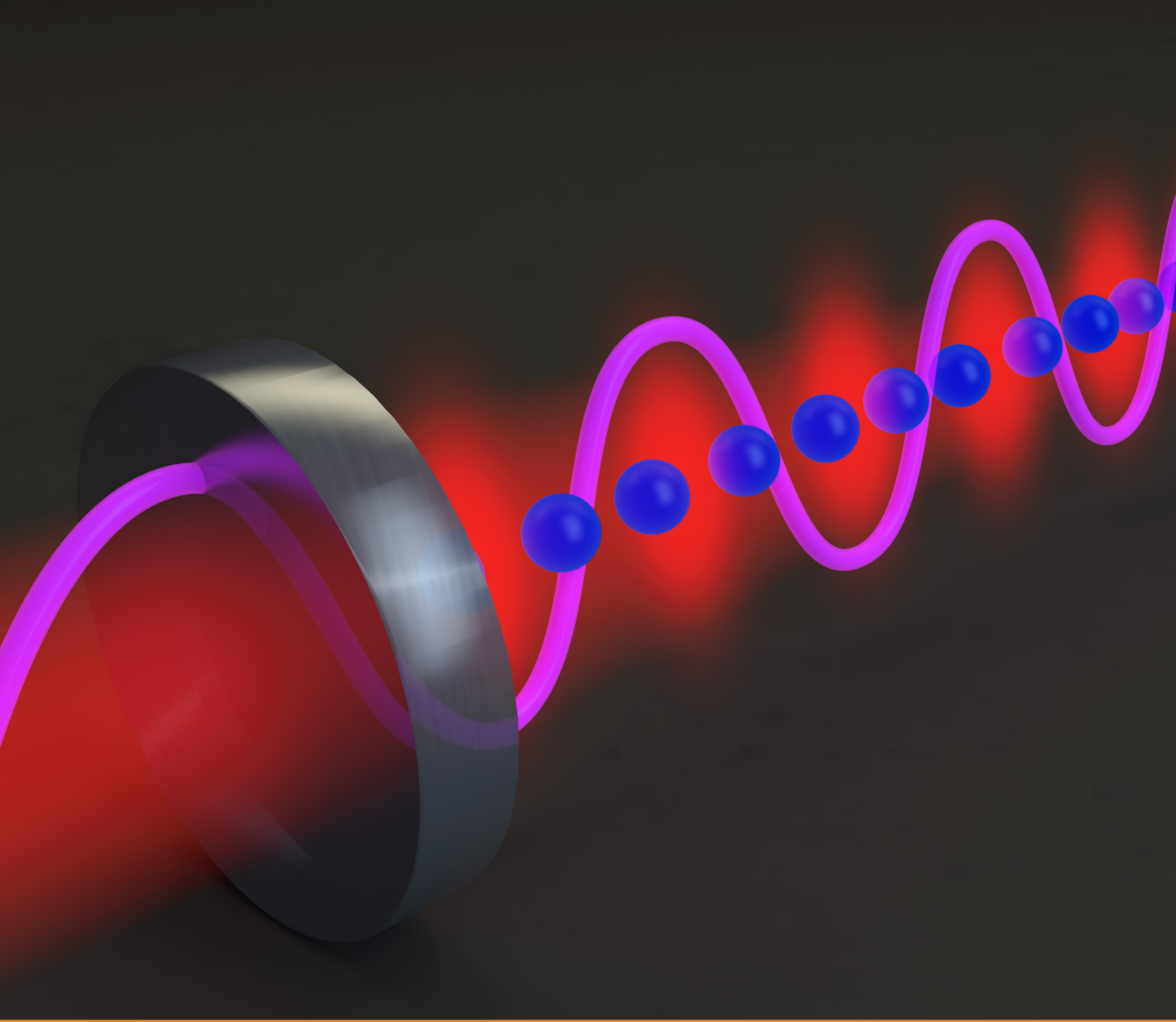
"This is actually the best of both worlds," explained Fellow Murray Holland. "You get the atoms really cold, and because of the superradiant effect, the plunging temperatures increase the number of photons being emitted by atoms, which makes the atoms slow down more rapidly and the cooling happen faster."

> "This is actually the best of both worlds," explained Fellow Murray Holland. "You get the atoms really cold, and because of the superradiant effect, the plunging temperatures increase the number of photons being emitted by atoms, which makes the atoms slow down more rapidly and the cooling happen faster."

The idea for superradiant laser cooling is so new, Holland and his group don't yet know its limits. Finding those limits may be a hard problem to solve because of the sheer difficulty of calculating the behavior of systems with many particles within the framework of quantum theories.

"We know that it gets very cold," Holland said. "It gets down to the recoil limit, which is the limit for most laser-cooling schemes." He noted that, in theory, it only takes about 20 atoms under superradiant conditions to cool down to just above absolute zero. He's eager to see what would happen in an experiment using 10,000 to 100,000 atoms.

Holland may soon get his wish, says experimentalist James Thompson.



New theory from the Holland group predicts that superradiant atoms that "talk" to each other may be able to promote collective laser cooling that may occur faster than single-atom laser cooling and reach even lower temperatures. Credit: The Holland group and Steve Burrows, JILA

"The Holland group's idea is really exciting because it moves laser cooling into a whole new regime in which having many atoms present is fundamental to the cooling," said Thompson. "This idea is very different from previous laser-cooling techniques that have been used to cool single atoms, molecules, and micromechanical objects.

"My group is anxious to see if we can build an experiment to see this collective cooling in action." ✺

Minghui Xu, Simon B. Jäger, S. Schütz, J. Cooper, Giovanna Morigi, and M. J. Holland, *Physical Review Letters* **116**, 153002 (2016).

How Did They Get Here?

Theorist **Ana Maria Rey** was appointed an Associate Fellow of JILA and Assistant Research Professor of Physics at the University of Colorado Boulder, in 2008. Since then she has done research on mathematical models to describe how nature behaves—in all its amazing complexity. She specializes in the scientific interface between atomic, molecular, and optical physics, condensed matter, and quantum information science. She investigates new techniques for controlling quantum systems and then uses them in applications ranging from quantum simulations and quantum information to precision measurement, primarily with time and frequency standards. Her long-term goal is to engineer controllable quantum systems that mimic real materials and develop advanced measurement techniques to probe atom-based quantum systems.

In 2012, Rey was appointed a Fellow of JILA and Associate Research Professor of Physics at CU Boulder. She is continuing her investigations of quantum simulation, quantum information, and precision measurement with investigations of (1) alkaline earth atoms such as strontium and ytterbium, (2) polar molecules such as ultracold potassium-rubidium (KRb) molecules, (3) trapped ions, and (4) nonequilibrium dynamics of atomic systems. Her research goals include the creation of new kinds

Credit: John D. & Catherine T. MacArthur Foundation of matter as well as the use of trapped ions and polar molecules to simulate quantum magetism and other quantum behaviors.

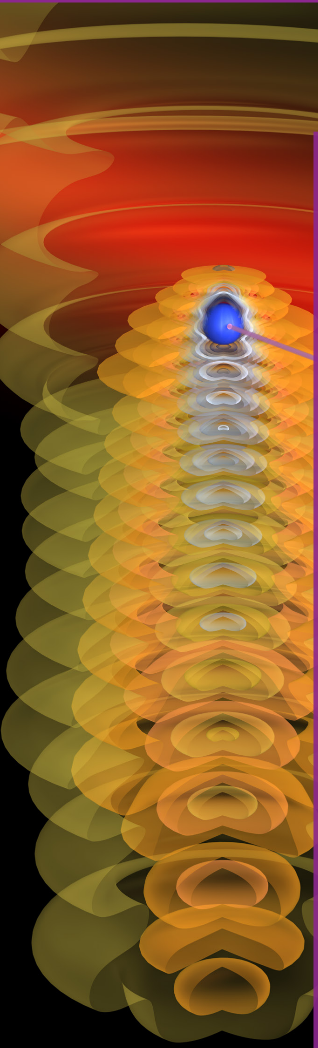
Rey received her Bachelor's degree in physics in 1999 from the Universidad de los Andes in Bogotá, Colombia. Next, she worked with Charles Clark at the National Institute of Standards and Technology (NIST) in Gaithersburg on the dynamics of strongly interacting atoms in optical lattices. As part of her research, she contacted Maryland cosmologist Bei-Lok Hu to help her adapt relativistic techniques to the study of nonequilibrium lattice dynamics. This work led to her being awarded the American Physical Society's Division of Atomic, Molecular, and Optical Physics (DAMOP) thesis prize in 2005. Rey was awarded a postdoctoral fellowship at the Institute for Theoretical Atomic Molecular and Optical Physics (ITAMP) at the Harvard-Smithsonian Center for Astrophysics and the Harvard University Physics Department where Rey collaborated with Mikhail Lukin and Eugene Demler.

Rey's research in atomic, molecular, and optical physics has received widespread recognition in recent years. In 2012, she was named "Woman Physicist of the Month" by the American Physical Society. In 2013, she received the "Great Minds in STEM" Most Promising Scientist Award, the American Physical Society's Maria Goeppert Mayer Award, and a Presidential Early Career Award for Scientists and Engineers. In 2013, Rey was named a 2014 MacArthur Foundation Fellow.

When Rey is not busy modeling the quantum world, she spends time with her husband Juan Gabriel Restrepo, Assistant Professor of Applied Mathematics at CU Boulder, and their son.

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

University of Colorado **Boulder** NIST

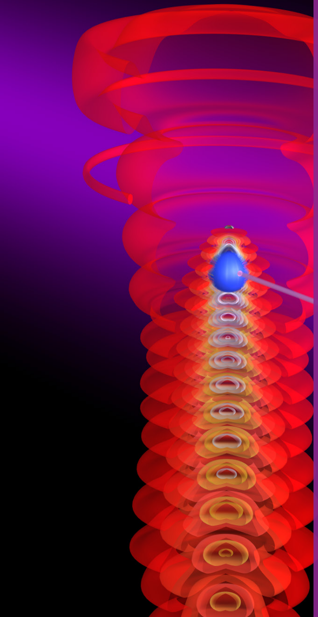


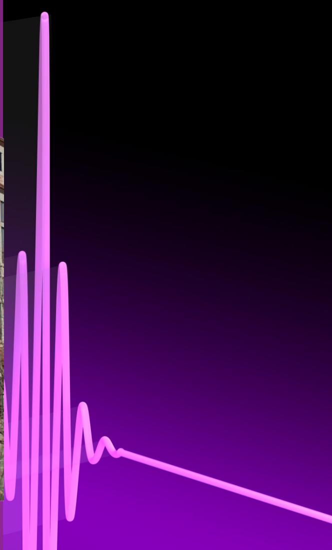
About JILA

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; Astrophysics & Planetary Science; Chemistry and Biochemistry; and Molecular, Cellular, and Developmental Biology as well as in the School of Engineering. NIST's Quantum Physics Division members hold adjoint 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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