JILA
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GAMMA-RAY EXPOSÉ
p.3

There were 54 entries in the 2015 JILA Photography contest held in April. Who knew there was so much artistic JILA talent?

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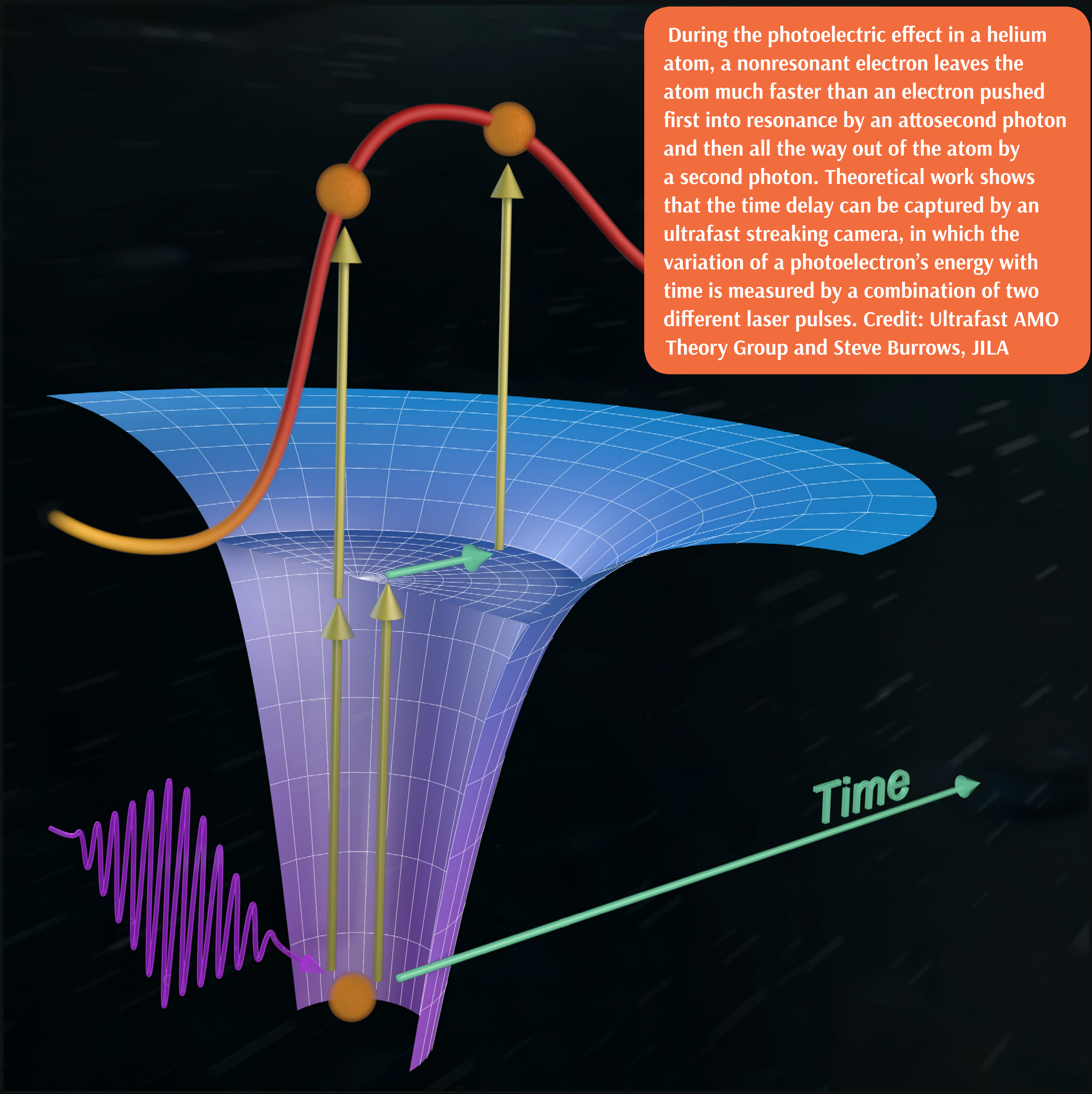
Stories

Features



During the photoelectric effect in a helium atom, a nonresonant electron leaves the atom much faster than an electron pushed first into resonance by an attosecond photon and then all the way out of the atom by a second photon. Theoretical work shows that the time delay can be captured by an ultrafast streaking camera, in which the variation of a photoelectron's energy with time is measured by a combination of two different laser pulses. Credit: Ultrafast AMO Theory Group and Steve Burrows, JILA

An Ultrafast Photoelectric Adventure

Such an experiment would open the door to observations of the behavior of electrons inside different atoms and molecules during the photoelectric effect.

The photoelectric effect has been well known since the publication of Albert Einstein's 1905 paper explaining that quantized particles of light can stimulate the emission of electrons from materials. The nature of this quantum mechanical effect is closely related to the question of how much time it might take for an electron to leave a material such as a helium (He) atom. The exciting news at JILA is that the Ultrafast AMO Theory Group has come up with a clever way that may help to answer this question by observing a photoelectron on its way out of, *but still inside*, an atom.

The theorists show how a combination of attosecond (10^{-18} s) and femtosecond (10^{-15} s) laser pulses could be used in the laboratory to follow the electrons inside a He atom on an ultrafast time scale. Such an experiment would open the door to observations of the behavior of electrons inside different atoms and molecules during the photoelectric effect. This seminal work appeared in an article published online December 24, 2014, in *Physical Review Letters*.

The researchers responsible for proposing the use of ultrafast laser pulses to really see something happening inside an atom include recently minted JILA Ph.D.s Jing Su and Hongcheng Ni as well as Associate Fellow Agnieszka Jaroń-Becker and Fellow Andreas Becker.

Their secret was to use a streaking camera, in which the variation of the photoelectron's energy with time is measured by the combination of two different laser pulses. First, one or two photons from the attosecond laser pulse kick the electron out of its ground state inside the atom. Then, the photoelectron interacts and oscillates in the electric field of the second, longer femtosecond laser pulse. The femtosecond laser field changes the energy of the electron depending on the time for the photoelectric effect to happen. This allows the researchers to probe the electron's behavior inside the atom (or molecule) during the photoelectric effect.

For example, if an attosecond photon kicks the electron first into resonance with one of the higher energy states in the atom, then the electron hangs out a while in the excited state before a second photon finally pushes the electron all the way out of the atom. The femtosecond laser pulse in the streaking camera measures the time the electron takes to move through and leave the atom.

In contrast, if the photon of the attosecond laser doesn't kick a helium electron into resonance, the electron is immediately pushed out of the atom. The femtosecond pulse instantaneously captures this behavior. In this way, the streaking camera may make it possible for researchers to observe and follow the kicking of an electron into a resonance state in real time. They may also be able to answer the question of how much it prolongs the photoelectric process inside the atom.

Jaroń-Becker, Becker, and their colleagues have opened the door to watching the inner workings of an atom during the photoelectric absorption and emission process. Now they have to wait and see if experimentalists can actually accomplish this feat in the laboratory. In the meantime, the Ultrafast AMO Theory Group is beginning work on using a streaking camera to peer inside other atoms and molecules. Stay tuned.✺

Jing Su, Hongcheng Ni, Agnieszka Jaroń-Becker and Andreas Becker, *Physical Review Letters* **113**, 263002 (2014).

Gamma-Ray Exposé

Supermassive black holes at the center of active galaxies are known as blazars when they are extremely bright and produce powerful jets of matter and radiation visible along the line of sight to the Earth.

Blazars can appear up to a thousand times more luminous than ordinary galaxies, and their associated jets are so powerful they can travel millions of light years across the Universe. Blazar jets produce flares of high-energy gamma rays that are detected by ground- and space-based observatories.

Nalewajko and his colleagues showed that gamma rays are most likely produced in jets at distances from a supermassive black hole ranging from 0.3 to 3 light years.

Locating the sites where gamma rays are produced in the jets, determining how fast they travel, and understanding how they are produced are important goals of many astrophysicists, including former research associate Krzysztof Nalewajko, Fellow Mitchell C. Begelman, and Visiting Fellow Marek Sikora of Poland's Nicolaus Copernicus Astronomical Center.

Nalewajko and his colleagues recently analyzed data from actual gamma-ray flares gathered by the Fermi Gamma-Ray Space Telescope and applied three plausible physical constraints in order to estimate the distance from the black hole at which those flares are produced in the jets.

The first constraint was that the jet is narrow enough to allow it to respond to the rapid changes in its environment. The second constraint was that the jet is fast enough to suppress x-ray emission associated with any gamma-ray flares below the observed level. The third constraint was that the cooling of energetic electrons is fast enough to be consistent with the observed time scale.

Using these constraints, Nalewajko and his colleagues showed that gamma rays are most likely produced in jets at distances from a supermassive black hole ranging from 0.3 to 3 light years. This distance is actually quite close to the black hole, considering the millions of light years typically traveled by high-energy jets. The researchers were also able to use constraints to estimate the energy content and composition of the jets.

This analysis contradicts some estimates based on high-resolution radio observations that gamma rays can be produced at distances up to 30 light years. It also opens the door to new theoretical and observational studies of the three constraints upon which this work relies.✺

Krzysztof Nalewajko, Mitchell C. Begelman, and Marek Sikora, *The Astrophysical Journal* **789**, 161 (2014).

Supermassive black holes at the center of active galaxies known as blazars produce powerful jets of matter and radiation visible along the line of sight to the Earth. A new study by Nalewajko et al. suggests that gamma-ray flares can be produced in these jets at distances from the black hole ranging from 0.3 to 3 light years. Credit: The Begelman group and Steve Burrows, JILA

IN THE NEWS

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

Margaret Murnane elected to the American Philosophical Society

JILA Fellow and University of Colorado Distinguished Professor of Physics Margaret Murnane has been elected to the American Philosophical Society in Class 1: Mathematical and Physical Sciences. She received the honor in April 2015.

The American Philosophical Society was founded in 1743 and is the first "learned" society of United States. Tom Cech is currently a member, and Kenneth Boulding and Gilbert White were formerly members. The society promotes useful knowledge in the sciences and humanities through excellence in scholarly research, professional meetings, publications, library resources, and community outreach. It has played an important role in American cultural and intellectual life for more than 270 years.

Ana Maria Rey Awarded American Physical Society Fellowship

Ana Maria Rey has been awarded an APS Fellowship by the American Physical Society. The award cited "her pioneering research on developing fundamental understanding and control of novel quantum systems and finding applications for a wide range of scientific fields including quantum metrology and the emerging interface between Atomic, Molecular, and Optical physics, consensed matter, and quantum information science."

Margaret Murnane Stars in New NSF Video

Recently, after delivering a lecture on ultrafast lasers and their applications for nanotechnology and materials research at the National Science Foundation, NSF Public Affairs Specialist Ivy Kupec and Margaret Murnane talked in front of the camera about super speedy lasers, science, and even Archimedes. The result is a delightful video about Murnane's life and work.

Murnane, who grew up in County Limerick, Ireland is well known for her work in the field of laser science. She has been a professor at the University of Colorado since 1999, and is a member of the NSF-funded JILA Physics Frontier Center. She and husband Henry Kapteyn (also a JILA Fellow and with whom she owns a small laser company) are conducting pioneering research in ultrafast x-ray science.

The video is part of NSF's interview series called Ultrafast lasers and Archimedes–Scientists & Engineers on Sofas (and other furnishings), and is viewable at: https://goo.gl/i7jUpP.

Kathleen Hoogeboom-Pot Wins 2015 Best Student Paper Award

Kathleen Hoogeboom-Pot has won the Karel Urbanek Best Student Paper Award for 2015 at the SPIE conference on Metrology, Process Control, and Inspection for Microlithography. Her paper was entitled "Mechanical and thermal properties of nanomaterials at sub-50 nm dimensions characterized using coherent EUV beams." Hoogeboom-Pot received the award on February 26, 2015.

Margaret Murnane: Leading Light in Optics

JILA Fellow Margaret Murnane is one of three prominent scientists profiled in *Nature*'s "Optics: Leading lights; Shape it, squeeze it, energize it or tie it into knots. Scientists are taking light to new extremes," published online in *Nature* on February 11, 2015.

Murnane is the focus of the third profile, "Fast Light: Margaret Murnane creates ultrashort laser pulses on a tabletop." Her profile takes her from her unique childhood in Ireland through graduate school and a long and productive professional career in collaboration with her husband and chief collaborator, Fellow Henry Kapteyn. The two scientists are currently making headlines with one of their most recent inventions: a tabletop x-ray laser.

Read the article at: http://goo.gl/D0jptW.

Three JILAns Win 2015 NSF Graduate Research Fellowships

JILA graduate students Stephen Okoniewski (Perkins group), Jake Pettine (Nesbitt group), and Lindsay Sonderhouse (Ye group) have won coveted 2015 National Science Foundation Graduate Research Fellowships, NSF announced March 31. The five-year Graduate Research Fellowships provide three years of support, with a per-year stipend of $34,000 and cost of education allowance of $12,000. Tuition and fees are waived during the term of NSF support. "It's a very prestigious fellowship to win," said Sonderhouse. "It looks wonderful on our resumes, and it's great for our advisors."

Read the full story with details about what each researcher is studying at: https://goo.gl/oGmR36.

2015 JILA Undergraduates Graduating with Honors

Congratulations to the following scholars!

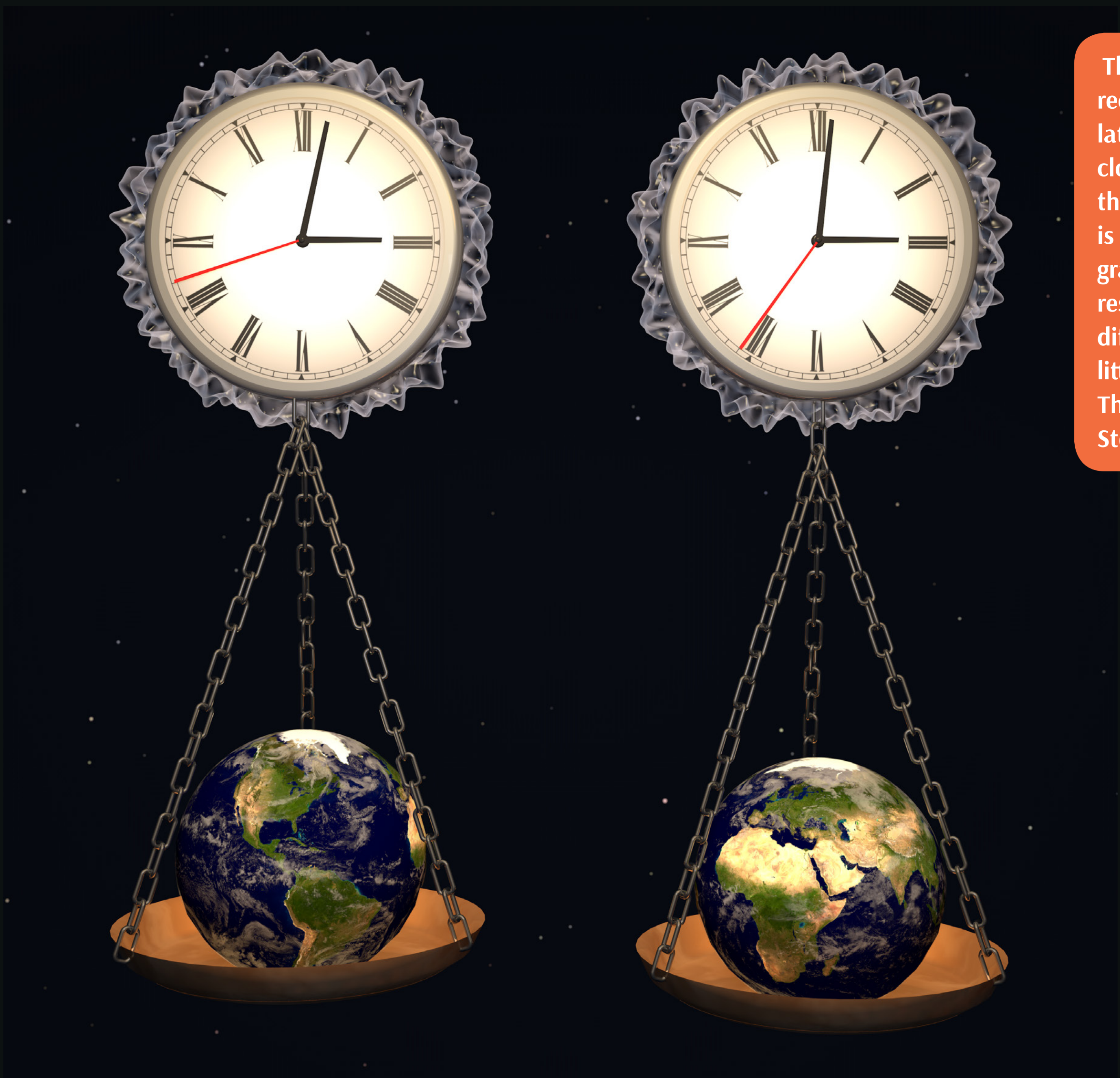
Conner Awe, magna cum laude
Steve Cundiff, Advisor
Andrew Barentine, magna cum laude
Heather Lewandowski and Eric Cornell, Advisors
Meaghan Daly, summa cum laude
Markus Raschke, Advisor
David Goldberger, summa cum laude
Debbie Jin, Advisor
Maithreyi Gopalakrishnan, summa cum laude
Henry Kapteyn, Advisor
Stephanie Hanshaw, summa cum laude
Heather Lewandowski, Advisor
Ran Reiff, summa cum laude
Andreas Becker, Advisor
Samantha Rubeck, summa cum laude
Dan Dessau, Advisor
Jamie Shaw, cum laude
Debbie Jin, Advisor
Jared Stanley, summa cum laude
Markus Raschke, Advisor

Carl Lineberger Wins 2015 NAS Award in Chemical Sciences

W. Carl Lineberger, JILA Fellow and E. U. Condon Distinguished Professor of Chemistry and Biochemistry at the University of Colorado, Boulder, has won the 2015 NAS Award in Chemical Sciences. He was recognized for the development of negative ion photoelectron spectroscopy, which scientists can use to determine the electron affinity of the neutral version of an atom or molecule. Electron affinity—the change in energy that occurs when an electron is added to an atom or molecule—provides important information about atoms and molecules and how they interact in chemical reactions. The "periodic table" of atomic electronic affinities now included in general chemistry textbooks is founded on Lineberger's early work with negative-ion photoelectron spectroscopy. His development of anion photoelectron spectroscopy as a tool to study small molecules has provided an important method to characterize highly reactive, short-lived species known as free radicals. This tool has also provided a new, direct way to observe the structure and evolution of molecules in the process of undergoing a chemical reaction. Lineberger's experimental methods are now in widespread use in laboratories throughout the world.

The NAS Award in Chemical Sciences was first awarded in 1979 to Linus Pauling for his studies that elucidated the properties of stable molecules of progressively higher significance to the chemical, geological, and biological sciences.

Will showers bring May flowers? Soggy sidewalks next to JILA's S- and X-Wings, within a quiet campus after the end of the semester.



The Ye group's most recent strontium lattice optical atomic clock is so sensitive that its timekeeping is affected by gravitational changes resulting from height differences of as little as 2 cm. Credit: The Ye group and Steve Burrows, JILA

About Time

Time is but the stream I go a-fishing in
--Henry David Thoreau

The Ye group has just improved the accuracy of the world's best optical atomic clock by another factor of three and set a new record for clock stability. The accuracy and stability of the improved strontium (Sr) lattice optical clocks is now about 2×10^{-18}, or the equivalent of not varying from perfect time by more than one second in 15 billion years—more than the age of the Universe. Clocks like the Ye Group's optical lattice clocks are now so exquisitely precise that they may have outpaced traditional applications for timekeeping such as navigation (GPS) and communications.

However, the new clocks promise to be excellent precision measurement tools for measuring Earth tides, improving our understanding of the basic shape of the Earth (geodesy), conducting tests of the fundamental laws that govern space and time, gaining a deeper understanding of the quantum world, and providing a novel pathway for investigating unknown phenomena such as dark matter.

On the flip side, the Ye group may have rendered impractical (for now) the concept of measuring and coordinating absolute time with such a super-accurate clock. The Ye group's accomplishments mean the global timekeepers will have to pioneer new ways to distribute such precise time and synchronize clocks across the world.

"We are walking through a portal where time itself is changing in response to changes in the shape of the Earth, and we used to think of time as a constant," explains Travis Nicholson, the lead graduate student on the project. "We were used to thinking the height of a mountain was a constant, too. All these things turn out to be a little bit fluid if your measurements are sensitive enough."

The Ye group's new optical atomic clock has this exquisite sensitivity because of a new state-of-the-art stable laser, improved measurement techniques, and better environmental controls, including more precise measurement and control of the temperature of the clock. The researchers responsible for the new clock include Nicholson, graduate students Sara Campbell and Ross Hutson, research associates Edward Marti and Wei Zhang, recent JILA Ph.D. Ben Bloom, CU undergraduate student Rees McNally, and colleagues from the University of Delaware, the National University of Singapore, the Joint Quantum Institute, and NIST Gaithersburg.

The new Sr lattice optical atomic clock is so sensitive that it would be affected by gravitational changes due to height differences of as little as 2 cm if researchers moved it up and down in the lab. With a clock this sensitive to small changes in gravity, the most stable clocks would need to be operated in space, far away from variations in local gravity. However, even with slightly less stable clocks, a future coordinated global timekeeping network would require detailed studies of Earth's gravity field to understand local gravitational effects on network clocks across the planet. At the very least, ultrasensitive clocks would have to work together in a network that is connected with phase-stable links since the time kept by these clocks would vary because of differences in local gravity. Another alternative would be to make the clocks portable so they could be directly calibrated against one another.

In addition to aiding in the coordination of global timekeeping, portable clocks would make it possible to precisely map the geoid, which is the shape that the surface of the oceans (extended through the continents) takes under the influence of Earth's gravitation and rotation. Portable clocks may also make it easier to measure changes in Earth tides (up and down movements of solid rocks) caused by the gravitational forces of the Moon and Sun.

Back in the Ye labs, the new clock could readily be adapted to (1) measure Earth's gravity variations if it works in tandem with a second, distant optical atomic clock such as the ytterbium optical lattice clock at NIST, (2) perform dark matter searches, (3) explore the intriguing quantum behavior of many atoms working collectively, and (4) probe deeply into the fundamental nature of light and matter.

Clearly, the world's newest and best optical atomic clock is about a lot more than time. It has become a precision tool for exploring the frontiers of physics.✺

T. L. Nicholson, S. L. Campbell, R. B. Hutson, Edward Marti, B. J. Bloom, R. L. McNally, W. Zhang, M. D. Barrett, M. S. Safronova, G. F. Strouse, W. L. Tew, and J. Ye, *Nature Communications* **6**, 6896 (2015).

Come CLOSER to Me

One of the great challenges in the semiconductor and electronics industries is that as nanoscale features get smaller and processes get faster, enormous amounts of heat need to be quickly carried away from the nanostructures. The Kapteyn/Murnane group has made the counterintuitive discovery that it is easier to cool these nanostructures when they are arranged closely together. The researchers also developed a theory to explain this unexpected new behavior.

In their experiments, the group cooled a collection of tiny hot nanowires embedded on substrates like silicon, sapphire, or other materials. When the nanostructures were heated with an infrared laser, they emitted phonons (lattice vibrations), which traveled into the substrate and collided with other phonons, carrying away the heat.

When the nanostructures were close together, there were more heat-dissipating collisions because phonons traveled shorter distances before colliding with another phonon. It made no difference to the cooling process whether the colliding phonons came from the same hot nanostructure or neighboring hot nanostructures. Thus, paradoxically, arranging the hot nanostructures more closely together actually enhanced heat dissipation.

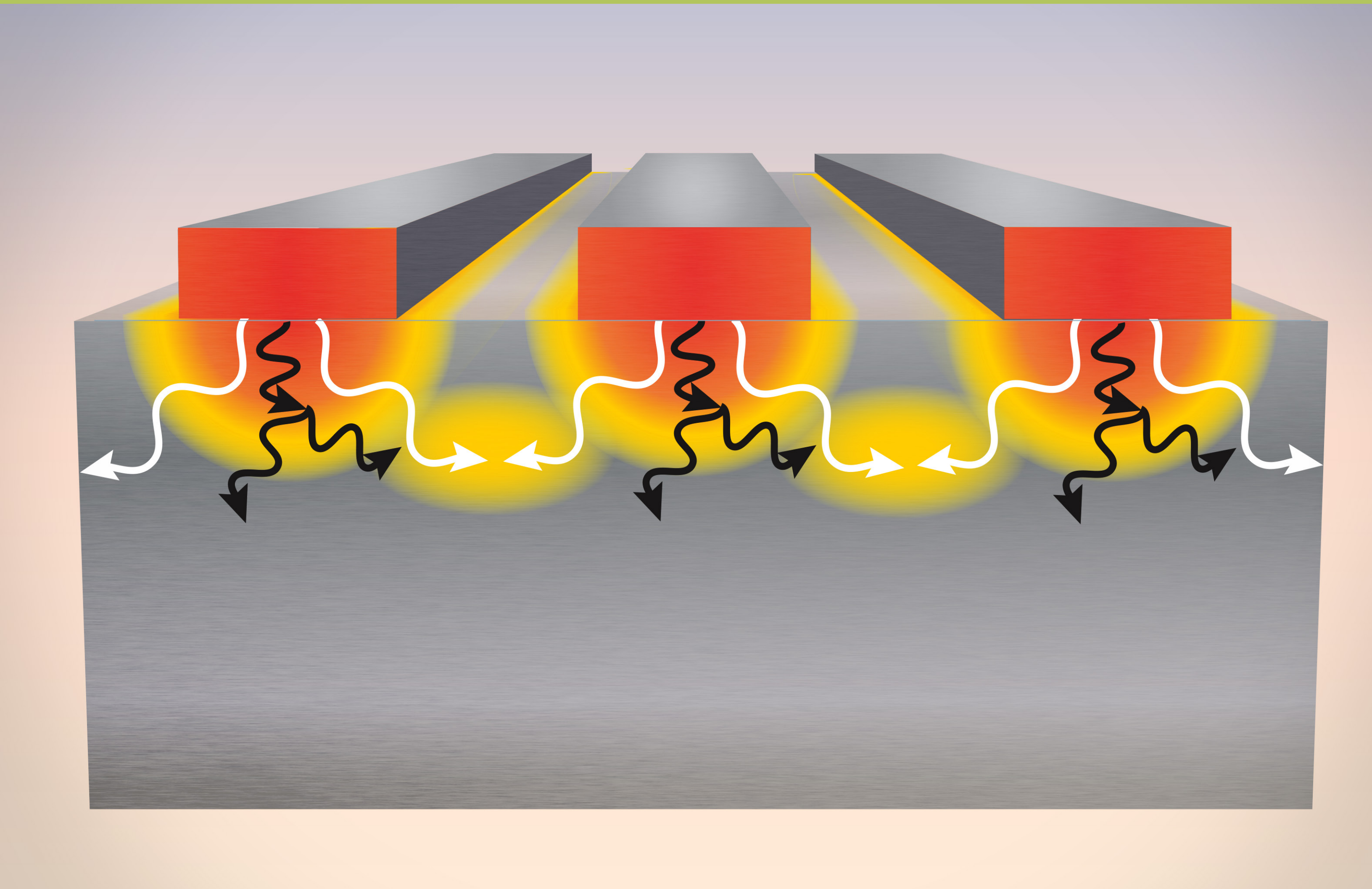
This result is exciting news for the field of nanoelectronics because in 2010 the Kapteyn/Murnane group showed that small, isolated hotspots are, in fact, quite challenging to cool.

What's interesting is that the nanowire size and spacing where these effects were seen is slightly different in silicon, sapphire, and other substrate materials. That's because the distance each phonon travels before colliding with another phonon is a distinctive feature of a particular substrate.

When they first observed this unexpected behavior, the researchers had to come up with a new theory to explain what was happening. They used the new theory to predict that nanowire heat sources would cool more rapidly when placed next to other heat sources than when they were isolated. Finally, they verified their new theory experimentally. In the process, they learned all kinds of interesting things about materials such as (1) exactly which vibrations carry heat away from a hot region and (2) new ways to engineer the cooling rate in a material.

The researchers include graduate students Kathy Hoogeboom-Pot, Jorge N. Hernandez-Charpak, and Travis Frazier, senior research associate Damiano Nardi, Fellows Margaret Murnane and Henry Kapteyn, as well as colleagues from CU's Department of Mechanical Engineering and the Lawrence Berkeley National Laboratory (Berkeley Lab). Their work was published online in March 2015 in the *Proceedings of the National Academy of Sciences*.

This work is expected to have a significant impact on the semiconductor and electronics industries where heat dissipation in nanostructures is a huge issue as industrial designers attempt to encapsulate more and more information into smaller and

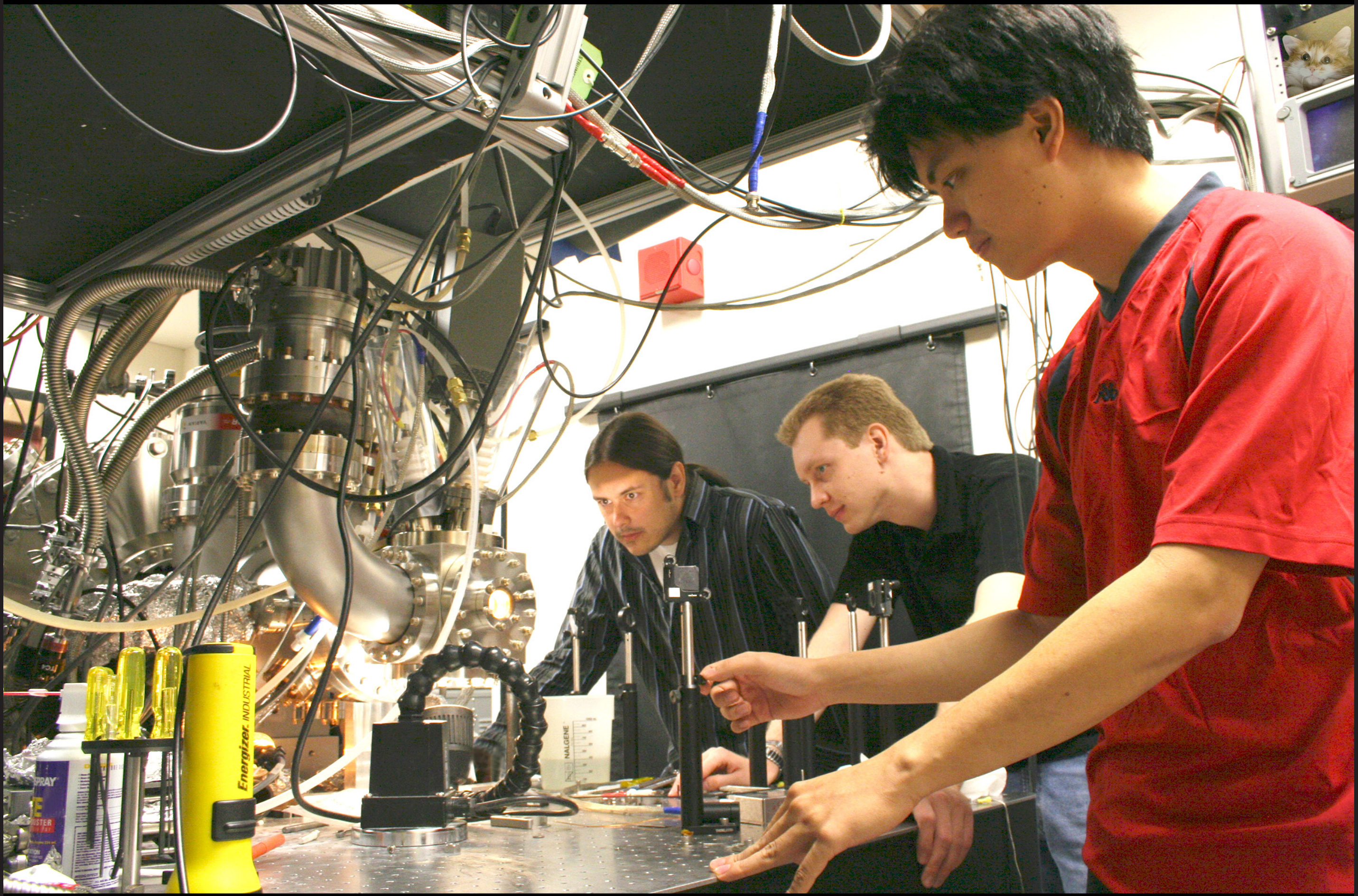


When closely spaced heated nickel nanowires emit lattice vibrations known as phonons into underlying materials, the phonons efficiently collide and transport heat away. This discovery has immediate application to the design of integrated circuits, nanoenhanced solar cells, and other electronics employing nanostructures. Credit: K. Hoogeboom-Pot and the Kapteyn/Murnane group, JILA

smaller spaces. It can be immediately applied to the design of integrated circuits, thermoelectric devices, heat therapies mediated via nanoparticles, and nanoenhanced solar cells used in clean energy technologies.✺

Kathleen M. Hoogeboom-Pot, Jorge N. Hernandez-Charpak, Xiaokun Gu, Travis D. Frazer, Erik H. Anderson, Weilun Chao, Roger W. Falcone, Ronggui Yang, Margaret M. Murnane, Henry C. Kapteyn, and Damiano Nardi, *Proceedings of the National Academy of Sciences USA* **112**, 4846–4851 (2015).

View Hoogeboom-Pot's video, "Nanoscale knowledge: Discovering how small is different" online at http://goo.gl/pwiUVy.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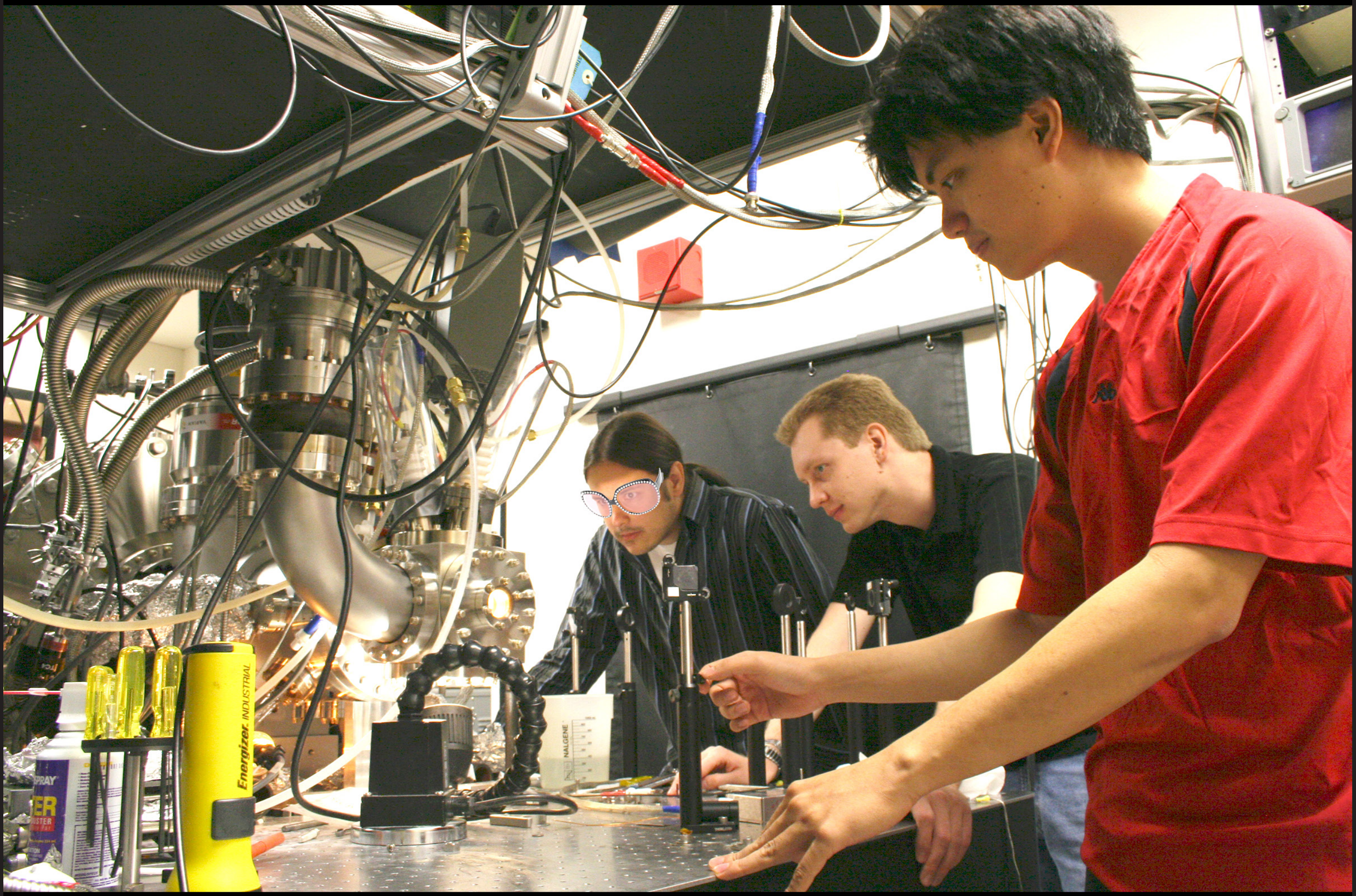
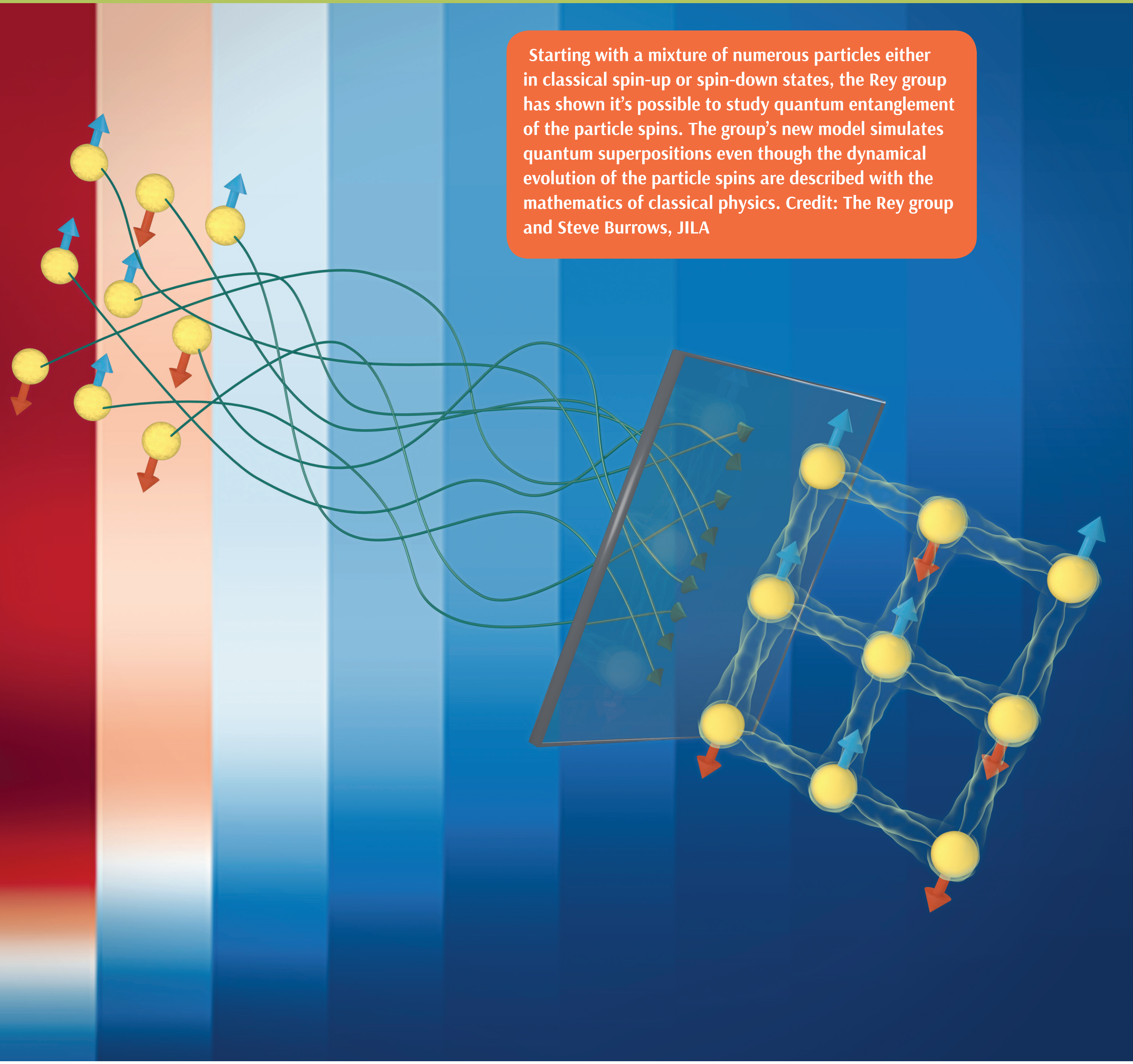

Energizer. INDUSTRIAL
NALGENE

Spot the Differences

There are 10 differences between the two lab photos. Either circle them on the photos or write them below. The first person to turn in a correct puzzle to Kristin Conrad (S264) will win a $25 Starbucks gift card.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________

Congratulations to Matt Grau (Cornell group), winner of the $25 gift card for solving the Winter 2015 crossword.



Starting with a mixture of numerous particles either in classical spin-up or spin-down states, the Rey group has shown it's possible to study quantum entanglement of the particle spins. The group's new model simulates quantum superpositions even though the dynamical evolution of the particle spins are described with the mathematics of classical physics. Credit: The Rey group and Steve Burrows, JILA

Terms of Entanglement

Innovative theory sheds light on complex quantum systems

When the Rey theory group first modeled a quantum system at JILA, it investigated the interactions of strontium (Sr) atoms in the Ye group's Sr lattice clock. The quantum behavior of these collective interactions was relatively simple to model. However, the group has now successfully tackled some more interesting systems, including the ultracold polar potassium-rubidium (KRb) molecule experiment run by the Jin and Ye groups. In the process, the group has developed a new theory that will open the door to probing quantum spin behavior in real materials; atomic, molecular and optical gases; and other complex systems. The new theory promises important insights into different areas of physics, quantum information science, and biology.

Thus, even though the researchers started out with a semiclassical description of spins, the end result was entanglement, as expected in a quantum mechanical system.

The new theory comes compliments of research associates Johannes Schachenmayer and Alexander Pikovski as well as Fellow Ana Maria Rey. It uses some clever classical techniques to model quantum spin dynamics. This capability is important because there is currently no computer powerful enough to handle a purely quantum description of the spins of particles in complicated systems that are not in equilibrium. Remarkably, the theory is also able to capture the long-range interactions where particles communicate information about the quantum state of their spins even to particles farther away.

The new approach starts with a mixture of many particles in classical spin-up or spin-down states. This statistical mixture aims to represent intrinsic correlations induced by the long-range interactions in a quantum state consisting of superpositions of particles in both possible spin states. Superpositions involving many particles are part of what is too complicated about quantum spin dynamics to analyze with today's supercomputers.

The researchers used a classical probability-based "Monte Carlo" method to create a mixture of spin-up and spin-down particles. Over time, they monitored the spin behaviors of the system as the spins evolved and observed the development of correlations between pairs of spins. Eventually the spins became entangled, just as one would expect if the system had been modeled quantum mechanically rather than classically. Entanglement means that the particles became informed of the state of their partners and, if something happens to one of them, all of the particles respond.

Thus, even though the researchers started out with a semiclassical description of spins, the end result was entanglement, as expected in a quantum mechanical system.

What's more, the new theory accurately predicts many aspects of spin dynamics predicted by previous analyses and calculations. This new method is expected to help theorists model the quantum spin behaviors observed in the JILA cold polar molecule experiment and other complex, out-of-equilibrium systems.✺

J. Schachenmayer, A. Pikovski, and A. M. Rey, *Physical Review X* **5**, 011022 (2015).

A Bug's Life

The Ye Group recently investigated what first appeared to be a "bug" in an experiment and made an unexpected discovery about a new way to generate high-harmonic light using molecular gases rather than gases of noble atoms.

Graduate student Craig Benko and his colleagues in the Ye group were studying the interaction of light from an extreme ultraviolet (XUV) frequency comb with molecules of nitrous oxide, or laughing gas (N_2O), when they noticed unusual perturbations in the laser spectrum. At first, the researchers thought the moving spectrum was some kind of bug they'd need to fix. But, like many unexpected observations in science, the "bug" turned out to be a sign the group had discovered something new and unexpected.

Benko, research associates Linqiang Hua and François Labaye, former research associate Tom Allison (now Assistant Professor of Physics and Chemistry at Stony Brook University), and Fellow Jun Ye decided to figure out exactly what was happening in their experiment. They considered whether the bug might have something to do with their new XUV frequency comb laser.

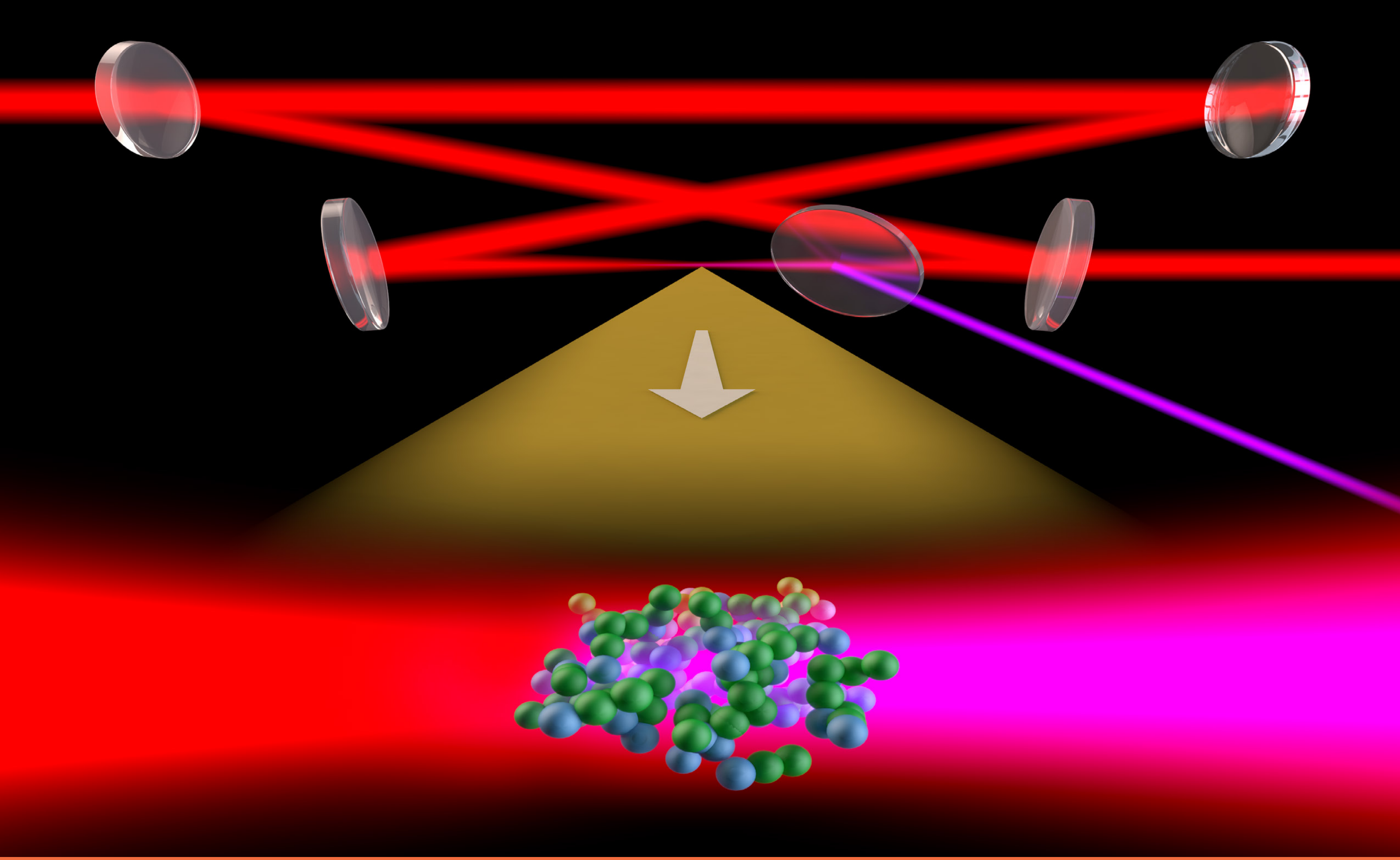
Frequency comb lasers do not usually have sufficiently powerful pulse peaks to control the behavior of molecules. However, in this experiment, the researchers used an optical cavity to bounce the laser light back and forth multiple times, increasing the laser's power. With this powerful new, precise ruler of light, they were not only able to observe the mystery of the moving spectrum, but also investigate it.

The researchers used the powerful laser to send two trains of pulses inside the cavity. They observed that the laser field of the first pulse "kicked" the N_2O molecules, which made the stick-shaped molecules line up parallel to each other. In other words, they became aligned with respect to the laser field. As the first laser pulse passed, the molecules started to tumble in unison, then periodically realigned as time went on. The frequency comb laser in the cavity made it possible to align the molecules more than 100 million times per second (as compared to 1000 times per second in previous experiments.)

As the molecules were tumbling, the researchers aimed a second, much more intense pulse at the molecules, sometimes when they were aligned and sometimes when they were not. Either way, the more intense pulse initiated high-harmonic generation. High-harmonic generation occurs when laser-stimulated atoms or molecules emit light consisting of higher harmonics of the fundamental frequency of the driving laser.

However, the second, more intense laser pulses were also partly responsible for the spectral perturbations! The "bug" in the system turned out to be an energy exchange between the molecules and the laser. The energy exchange caused the laser spectrum to move around. By studying this process, the researchers observed that the time delay between the two laser pulses determined whether the molecules stole energy from the laser pulse, or gave some back.

By adjusting the timing of the two pulses, the researchers discovered they had the makings of an excellent tool for investigating the physics of the N_2O molecules used for the high-harmonic

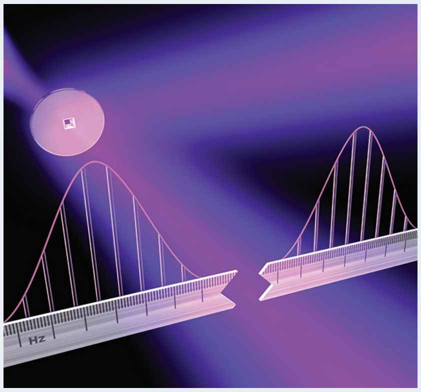


A pulse from a powerful laser can align stick-shaped molecules of laughing gas (N_2O) inside an optical cavity up to 100 million times a second. A second laser pulse can then initiate high-harmonic generation, a process that occurs when laser-stimulated atoms or molecules emit light of higher harmonics of the fundamental frequency of the laser. Credit: The Ye group and Steve Burrows, JILA

generation! Consequently, the researchers plan to use two XUV combs working in tandem (a process described in "Invisible Rulers of Light") to probe the behavior of the N_2O molecules during high-harmonic generation.

As it turns out, the "buggy" experiment has opened the door to studies of high-harmonic generation in molecules and comparisons of this process with the more traditional high-harmonic generation using noble gas atoms such as xenon. Since xenon atoms are spheres, a comparison of their high-harmonic generation with high-harmonic generation with stick-like N_2O molecules should yield some interesting new physics. Stay tuned.✺

Craig Benko, Linqiang Hua, Thomas K. Allison, François Labaye, and Jun Ye, *Physical Review Letters* **114**, 153011 (2015).



For more background on the research that lead to this breakthrough, read "Invisible Rulers of Light" at https://goo.gl/50YcoC; or, in the Fall 2014 issue of *JILA Light & Matter*.

JILA Associate Fellow

Agnieszka Jaroń-Becker

Agnieszka Jaroń-Becker is Associate Research Professor of Physics at the University of Colorado, Boulder, and Associate JILA Fellow. In JILA, she serves as co-director of JILA's Ultrafast Theory Group, which specializes in theoretical studies of ultrafast processes in atoms, molecules, and nanostructures. These ultrafast processes are induced, observed, and controlled by ultrashort intense laser pulses. The laser frequencies studied range from the far infrared through the optical to the soft x-ray region of the electromagnetic spectrum.

Jaroń-Becker completed her undergraduate, master's, and doctoral studies at Warsaw University's Institute of Theoretical Physics in Warsaw, Poland. She earned her master's degree in 1996, and her doctorate in 2001. Since that time, she has built upon her doctoral work in multiphoton processes in intense laser fields.

Prior to coming to JILA, Jaroń-Becker was Assistant Professor of Physics at Warsaw University from 2001 to 2005. During this time, she also received an Alexander von Humboldt Postdoctoral Fellowship for postgraduate work at the University of Bielefeld, Germany (2002–2003). She completed additional postdoctoral work at the Max Planck Institute for the Physics of Complex Systems, Germany (2004–2005). From 2005 to 2008, she was Senior Research Associate at the Technical University of Dresden Institute of Physical Chemistry, also in Germany.

Jaroń-Becker came to JILA in 2008. She was appointed JILA Associate Fellow in 2014 after serving three–year terms as Research Associate and Senior Research Associate. She currently serves as a member of the Executive Committee of the Topical Group of Few Body and Multielectron Dynamics of the American Physical Society. She received an NSF Theoretical, Molecular, and Optical Physics (TAMOP) award in 2011 and an Air Force Office of Scientific Research MURI award in 2010.

Fellows Adjunct

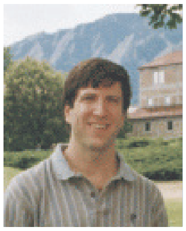
JILA is pleased to announce that Dan Dessau and Thomas Schibli join Markus Raschke as JILA Fellows Adjunct.

Thomas Schibli

After obtaining a diploma in physics from the Swiss Federal Institute of Technology (ETH) in his hometown, Zurich, Switzerland, Schibli joined the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, where he wrote a diploma thesis. In 1999 he joined the Institute of Quantum Electronics at the University of Karlsruhe, Germany, where he obtained his Ph.D. in 2001. He then spent another two years at MIT (at the Research Laboratory of Electronics and the Center for Ultracold Atoms) as a postdoctoral associate, working on ultrashort pulse generation, optical frequency combs and precise synchronization techniques for optical metrology, and timing distribution. From 2003–2006 Schibli worked as a researcher at the Institute of Advanced Industrial Science and Technology and the National Metrology Laboratory of Japan (AIST/NMIJ) in Tsukuba, Japan, where he developed fiber laser-based frequency combs for molecular spectroscopy and novel techniques for sub-pm dimensional metrology based on a wavelength-stabilized optical comb. In 2006, he joined JILA where he worked as a senior research associate for two years on XUV frequency comb generation. He joined the Department of Physics in the fall of 2008 as an assistant professor under the optics initiative.

Fellow Adjunct Schibli's current research interests are the fields of ultrafast physics, tools and applications for precision optical metrology, and the design, synthesis and spectroscopy of low-dimensional nonlinear optical materials. He says, "I'm delighted to be in Boulder. It offers great minds and a perfect environment in which to work!"

Dan Dessau



Fellow Adjunct Dan Dessau is Professor of Physics at the University of Colorado, Boulder. His research focuses on using femtosecond optics and electron spectroscopic tools to investigate the electronic structure, magnetic structure, and phase transitions of high-temperature superconductors, topological insulators, "heavy" quantum materials (such as iridates), organic materials for photovoltaics, and colossal magnetoresistive oxides.

The Dessau lab was the first to demonstrate laser angle-resolved photoemission spectroscopy (ARPES). Currently, the lab is home to both the highest energy-resolution and lowest-temperature ARPES facility in the United States and a novel femtosecond time-resolved ARPES system. The Dessau group also uses advanced synchrotron instruments around the world for ARPES and other techniques such as x-ray absorption spectroscopy and resonant x-ray scattering.

How Did They Get Here?

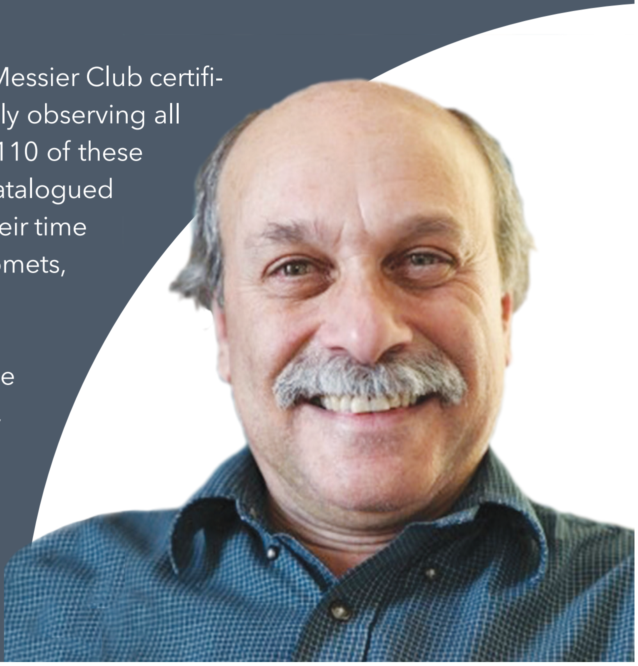
Mitch Begelman decided he wanted to be an astrophysicist when he was five years old and living in the Bronx, New York, with his parents Irving and Barbara. In 1958, he saw a Walt Disney program about interplanetary space travel and immediately knew science was for him. To his delight, his parents gave him a small refracting telescope for his 6th birthday. He soon became an active amateur astronomer.

Begelman was an observational astronomer through high school. His astronomy club used to rent a cottage in the Catskills, and that was where he did most of his observing. He also observed from the roof of his family's six-story apartment building in the Bronx, which was on a major street called the Grand Concourse. He saw the aurora borealis for the first time from the Grand Concourse.

During junior high, and later at the Bronx High School of Science, he was involved in the Amateur Astronomers Association of New York, which was then based in the old Hayden Planetarium in the Museum of Natural History in New York City. He served as the Deep Sky Recorder and later as the Planetary Recorder. This group met monthly, but older people dominated those meetings. However, Begelman was also active in the Amateur Observers Society of New York, based in Queens. The Amateur Observers Society was entirely composed of high-school students.

Begelman remembers those days fondly. He and his friends organized expeditions. They once got the 86th floor observation deck of the Empire State Building all night to observe a lunar eclipse. One memorable daytime observation was the transit of Mercury across the Sun. The group even had its picture taken and displayed on the cover of the (New York) *Daily News* and the *New York Post*. The amateur astronomers also organized a trip to North Carolina to view a total eclipse of the Sun in March of 1970.

Begelman was one of the first people to earn a Messier Club certificate from the Astronomical League for personally observing all the Messier objects in the sky. There are about 110 of these fuzzy-looking, immobile objects. Messier catalogued them as a way of warning people not to waste their time looking at them if they wanted to discover comets, which move across the sky.



Begelman, of course, was fascinated by the Messier objects, which are a mixture of galaxies, clusters of stars, and nebulae. M1, for example, is the Crab Nebula, which Begelman observed many times with his telescope (by then upgraded to a 6-in reflector) during high school. Not surprisingly—for a man who ponders the same questions through many decades—the Crab Nebula has been the subject of at least a dozen papers written by Begelman and colleagues at the University of Colorado aimed at explaining important new gamma-ray discoveries.

When Begelman went to Harvard in 1970, he decided to major in physics. Most of the time he was there, he didn't know what kind of physics he wanted to specialize in. In his last year, not surprisingly, he decided to go into astrophysics after completing some interesting undergraduate research on spinning-magnetized dust grains in interstellar space and on the atmosphere of Venus. Begelman graduated from Harvard in 1974 with bachelor's and master's degrees in physics. Next, he started graduate school at the University of Cambridge, concentrating in theoretical astrophysics.

At Cambridge he went to work with Martin Rees, a young professor studying quasars, cosmology, and black holes. Begelman decided to work on black holes, which was a somewhat risky choice in the mid-1970s because most people still didn't believe black holes actually existed. Begelman and Rees decided to see if they could explain the phenomena being observed that supported the idea of black holes, but without having a black hole. The goal was to see if they could rule out all the alternative explanations.

One of the biggest surprises of that time was the discovery of cosmic jets. No one expected black holes to eject much of the gas in their vicinity. Begelman worked on some of the early papers that attempted to understand the physics of jets, including one he co-authored with Roger Blandford and Rees in 1984 on the physics of jets, which remains his single most highly cited paper. He still explores the physics of jets.

Begelman's early explorations of black holes in graduate school led to decades of studies of black holes and a popular book on black holes entitled *Gravity's Fatal Attraction: Black Holes in the Universe*, jointly authored by Begelman and Rees. The book's first edition was published in 1996 and its second edition in 2009. He won the American Institute of Physics Science Writing Award for the first edition of the book.

He also authored *Turn Right at Orion*, a fictional memoir of what it would be like to travel around the Milky Way looking at weird objects, and then to fly to the Virgo Cluster to visit M87, a supergiant elliptical galaxy. Begelman has always enjoyed his popular science writing projects.

Begelman has many research interests in addition to black holes and jets. He studies interstellar and intergalactic gas, the interactions of very energetic particles (cosmic rays) with gas, and other topics exploring the physics of matter in very low-density areas between stars and between galaxies. This work, together with his explorations of the physics of black holes, is much easier today with the availability of supercomputers containing tens of thousands of processors running in parallel, capable of performing 250 years worth of simulation in a single day.

Though he has studied many other topics in astrophysics, Begelman is frequently drawn back into investigations of black holes. He finds it fascinating to explore a topic where so much is speculative and it's possible to dream about all sorts of processes that may occur, even though observational verification may be far in the future. He is quick to point out, however, that a surprising number of these seemingly wild speculations have ultimately received observational support.

A question he is currently asking is: how close to the speed of light can a jet of gas really get? Right now, no one knows what determines the speeds of jets. However, Begelman has a novel approach to solving this problem. He thinks that the jets whose speeds approach the speed of light are the ones that are not driven by magnetic fields. There's a reason he believes this even though he's about the only one who does. The reason is that if there's a magnetic field in a gas with very high speed, the magnetic field automatically generates an electric field because of induction. And, the electric field develops forces that are almost exactly equal and opposite to the forces of the magnetic field. Thus it's very hard to accelerate ionized gas beyond some large fraction of the speed of light. Consequently, the less acceleration depends on magnetic fields, the easier it is to attain ultra-high speeds. Begelman hypothesizes that's exactly what propulsion by radiation pressure—rather than magnetic fields—can accomplish in extreme environments.

Another novel investigation of his is the Zero-Bernoulli accretion flows, or ZEBRAs. A ZEBRA can form out of the debris from a star being sucked into a black hole. Depending on the angular momentum of the debris, accretion "disks" around black holes can form three-dimensional spheres with a jet coming out of a hole in their top. The stellar-like objects with a black hole (or neutron star) in the center are ZEBRAs. There may be other circumstances in extreme environments where ZEBRAs form as well.

Begelman is most attracted to the study of extreme phenomena such as ZEBRAs, jets, and black holes. He likes to investigate things in the Universe that are so far from what you see on Earth that a person has to use all the powers of his or her imagination as well as mathematics to understand what's going on. In other words, he jumps into topics where scientists just barely know what the relevant physics might even be. In the end, he loves to ask questions, especially questions no one else has thought of yet. He prefers coming at problems from creative new directions as well.

Begelman has given decades of professional service to such organizations as NASA, the American Astronomical Society, and the National Science Foundation. He has also won numerous honors and awards, including a Presidential Young Investigator Award in 1984, an Alfred P. Sloan Foundation Research Fellowship in 1987, and the Helen B. Warner Prize of the American Astronomical Society in 1988. He received University of Colorado Faculty Fellowships in 1990–1991, 1998–1999, and 2005–2006. He won a Guggenheim Fellowship in 1998–1999 and a Boulder Faculty Assembly Award for Excellence in Research, Scholarly, and Creative Work in 1999–2000. He was the first Boldt Lecturer at the NASA/Goddard Space Flight Center in 2004 and a Visiting Fellow Commoner at Trinity College, Cambridge in 2005–2006. He is a Fellow of the Royal Astronomical Society and the Cambridge Philosophical Society.

Read other bios at http://jila.colorad.edu/faculty/profiles-science.

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; Chemistry and Biochemistry; Astrophysical and Planetary Sciences; 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. Our scientists 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.

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