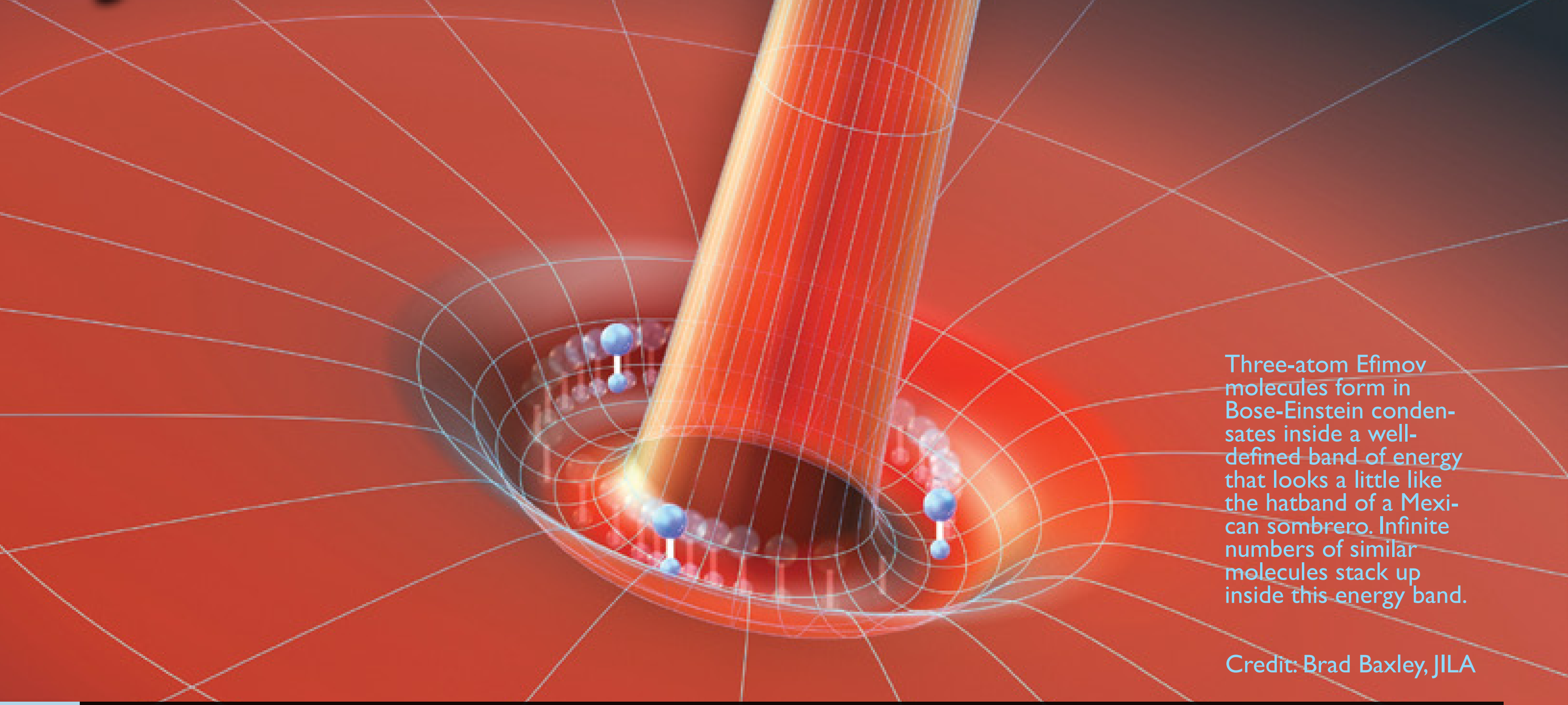
JILA LIGHT & MATTER

SUMMER 2011



Three-atom Efimov molecules form in Bose-Einstein condensates inside a well-defined band of energy that looks a little like the hatband of a Mexican sombrero. Infinite numbers of similar molecules stack up inside this energy band.

Credit: Brad Baxley, JILA

Laws of Attraction

There's exciting news in the field of Efimov physics!

In 1970, Russian theoretical physicist Vitaly Efimov predicted a strange form of matter called the Efimov state. In these strange states, three atoms can stick together in an infinite number of new quantum states, even though any two can't even form a molecule. For a long time, scientists were skeptical about Efimov's prediction. However, since the 1990s, Fellow Chris Greene's group (with J. P. Burke, JR. and Brett Esry) have expanded the theory of Efimov physics and predicted the experimental conditions under which Efimov states can be observed. In 2006, these strange states were observed experimentally for the first time.

Three-atom Efimov molecules (trimers) can form in Bose-Einstein condensates (BECs) or other ultracold gases. The Efimov trimers form because of a kind of memory "ghost" created through the attraction felt by the atoms only when they are stacked immediately on top of each other in an ultracold gas. This eerie attraction can lead to the formation of an endless sea of three bound quantum states, even when individual atoms are far apart.

Now, the Greene group has shown that dipolar Efimov trimers can also form in an ultracold system. Dipolar Efimov states are more peculiar than "ordinary" Efimov molecules. The strangest thing is that they exist at all. Theorists including senior research associate José D'Incao and Fellow Chris Greene once thought the Efimov effect would not occur with atoms and molecules in a strong electric field. However, the JILA researchers have just proved that they were mistaken.

Even though (1) the atoms in a dipolar Efimov trimer are normally very far apart and extremely weakly bound, and (2) an electric field exerts a pull on the dipolar trimers to align with the field, the Efimov effect persists in dipolar systems. In fact, in a dipole system, the stronger the electric field, the longer the Efimov molecules live! Dipolar Efimov states can survive long enough inside a dipolar gas that experimental physicists should be able to create and manipulate them in the laboratory.

This kind of survival is stunning when you consider that Efimov physics in an ultracold dipolar BEC is constrained by an electric field. However, the major constraint is not *if* the molecules can form. Rather, it is that Efimov trimers can only form inside a well-defined band of energy that looks a little like the hatband on a Mexican sombrero.

Chalk one up for the laws of attraction — and the utter weirdness of the quantum world. "The quantum world we study looks crazy, but it's actually real," says research associate Yujun Wang, who worked with D'Incao and Greene to probe the nature of the Efimov effect in an ultracold dipolar system. The researchers have predicted where in the system the Efimov states form. Once the molecules form, they are easy to see because they exhibit a clear mathematical signature. And, as soon as the first Efimov molecule appears in the system, the researchers are able to predict the energies of its sister molecules that form in limitless quantities in the same energy band. The researchers have also found a series of magic values for the electric field that led to the formation of an infinite number of Efimov states.

Not surprisingly, dipole interactions prevent the atoms in an Efimov trimer from getting too close together. And, if all the dipoles in a trimer do come close together, it is difficult to explain the physics of what happens. However, once the dipoles are far apart, the physics of their interactions becomes more universal and easier to describe mathematically. This discovery is a key insight for future ultracold molecule experiments because Efimov molecules can be destructive when they are unstable. Experimental physicists don't want unstable Efimov molecules knocking atoms out of an optical trap and destroying an ultracold system. Because Efimov molecules are more stable in an electric field, they'll also be much easier to study there.

Wang, D'Incao, and Greene hope that experimentalists will soon take up the challenge of studying Efimov states in ultracold gases in the presence of electric fields. In the meantime, though, the JILA theorists are now exploring the weird quantum states of ultracold dipolar fermions. Fermions cannot occupy the same quantum state, unlike the neighborly bosons, which happily form BECs at ultracold temperatures. So it isn't clear what will happen to dipolar fermions under conditions that would lead to the formation of Efimov molecules made of bosons. The Greene group hopes to find out soon.

Reference:

YuJun Wang, J. P. D'Incao, and Chris H. Greene, *Physical Review Letters* **106**, 233201 (2011).

REACTIONS ON DEMAND

Predrag Ranitovic dreams of controlling chemical reactions with ultrafast lasers. Now he and his colleagues in the Kapteyn/Murnane group are one step closer to bringing this dream into reality. The group recently used a femtosecond infrared (IR) laser and two extreme ultraviolet (XUV) harmonics created by the same laser to either ionize helium atoms or prevent ionization, depending on experimental conditions. The researchers adjusted experimental conditions to manipulate the electronic structure of the helium atoms as well as control the phase and amplitude of the XUV laser pulses.

The researchers modified the electronic structure of helium with the IR pulse that controls the amplitude of the XUV harmonics and the relative phase between the XUV and IR pulses. In so doing, they were able to create a quantum "double-slit" situation in which they could control the probability of ionization by interfering two electron waves constructively or destructively. If the interference was constructive, the IR-enhanced XUV pulses could knock an electron out of a helium atom, even though neither of the pulses was energetic enough by itself to remove one of helium's two electrons. In contrast, if the interference was destructive, the XUV pulses sailed through the helium atoms as if they weren't even there.

"We can send two ionizing pulses into an atom, but we can also make the atom not see them," Ranitovic said. "This is a novel way of doing coherent control." He explained that if the atom sees the pulses, it ionizes. But the atom can't ionize if it doesn't see the pulses. The process of keeping the atom from seeing ionizing pulses is called electromagnetically induced transparency.

The effort to understand and control electromagnetically induced transparency included research associate Ranitovic, graduate student Craig Hogle, former research associate Xibin Zhou, as well as Fellows Margaret Murnane and Henry Kapteyn. The JILA team collaborated with theorist colleagues at the University of Tsukuba (Japan) and the University of California, Berkeley.

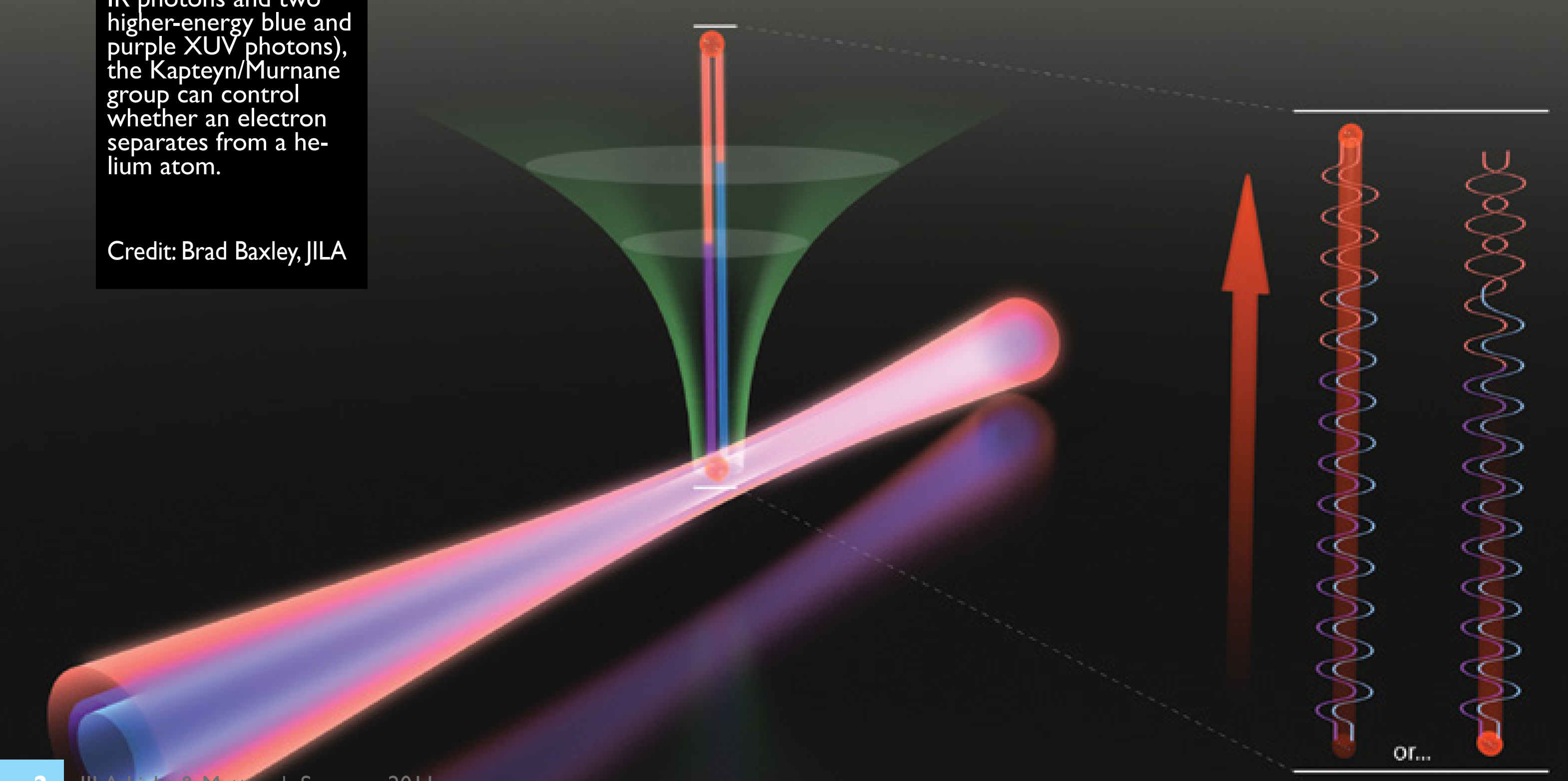
The theorists helped Ranitovic understand how the IR laser worked with the XUV pulses to ionize helium. The XUV pulses alone cannot ionize helium atoms; they can only excite them. Ionization requires additional energy from IR photons, 5 in the case of one of the XUV harmonics and 3 in the case of the other. The IR laser field also modifies the electronic structure of helium, making it easier for the researchers to control the ionization process.

Another way to think about helium ionization is that the three colors of light (i.e., red IR photons and two higher-energy purple and blue XUV photons) influence a helium electron. By adjusting the three colors, Ranitovic and his colleagues showed that they can launch an electron wave in a helium atom along two different quantum pathways. The wave traveling the different quantum pathways has the same amplitude but opposite phases. It cancels itself out on the way out of the helium atom, thus controlling the likelihood that an electron will separate from its parent atom. This new technique has great promise.

Ranitovic is now leading efforts to extend the new coherent-control scheme to simple molecules such as hydrogen or H_2. "Once we understand simple systems, we can apply our new technique to complex molecules and chemical reactions," Ranitovic said.

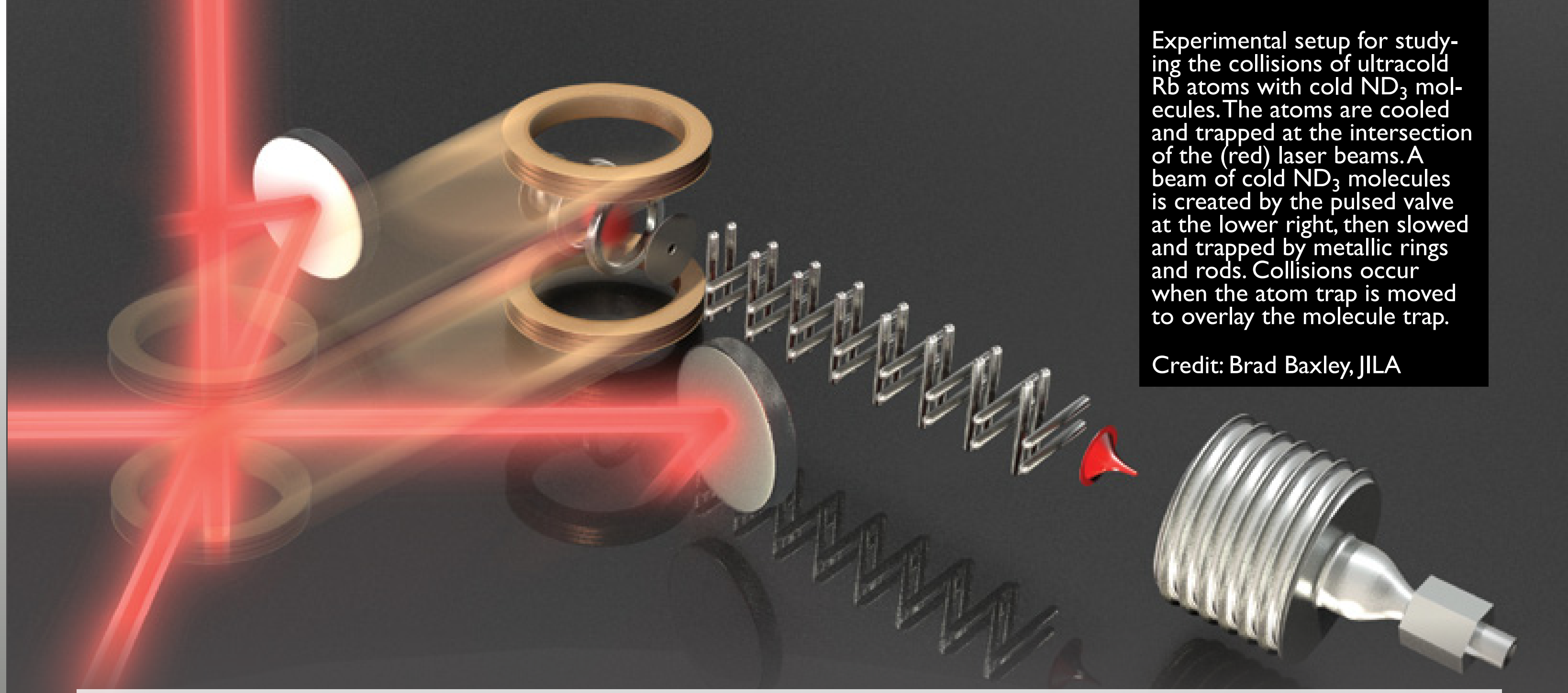
Reference:

P. Ranitovic, X. M. Tong, C. W. Hogle, X. Zhou, Y. Liu, N, Toshima, M. M. Murnane, and H. C. Kapteyn, *Physical Review Letters* **106**, 193008 (2001).



By adjusting three colors of light (red IR photons and two higher-energy blue and purple XUV photons), the Kapteyn/Murnane group can control whether an electron separates from a helium atom.

Credit: Brad Baxley, JILA



Experimental setup for studying the collisions of ultracold Rb atoms with cold ND_3 molecules. The atoms are cooled and trapped at the intersection of the (red) laser beams. A beam of cold ND_3 molecules is created by the pulsed valve at the lower right, then slowed and trapped by metallic rings and rods. Collisions occur when the atom trap is moved to overlay the molecule trap.

Credit: Brad Baxley, JILA

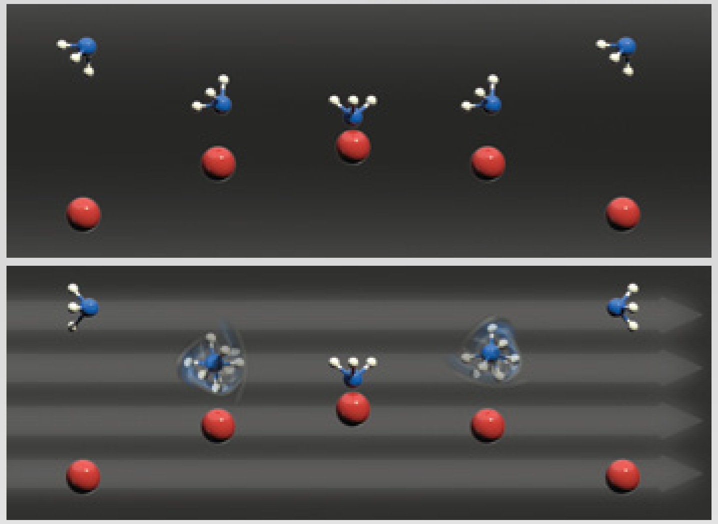
I Sing the Body Electric

The Lewandowski group recently decided to see what would happen if it could get cold molecules (1K–1mK) and ultracold (<1mK) atoms to collide. Former graduate student L. Paul Parazzoli, graduate student Noah Fitch, and Fellow Heather Lewandowski devised a novel experiment to determine the collision behavior of cold (100 mK) deuterated ammonia (ND3) molecules and ultracold (600 mK) rubidium (Rb) atoms. The researchers hoped their experiment would help elucidate the role of quantum mechanics in molecular collisions.

Their novel experimental setup is shown in the top picture. The researchers cool and trap Rb atoms at the intersection of the (red) laser-cooling beams. Then a pulsed valve (lower right) creates a beam of cold ND3 molecules. The metallic rods and rings create electric fields that slow and trap the molecular beam. To combine the cold molecules and ultracold atoms, the researchers physically move the coils forming the atom trap across the table until the atom trap overlays the molecule trap.

With the traps superimposed, atom-molecule collisions are likely to occur, according to theory. These collisions will have very little effect on an ND3 molecule. An ND3 molecule will usually remain in the same quantum state after a collision as it was in before anything happened.

To liven up their experiment, the researchers decided to see how electric fields would affect these unusual collisions. They quickly discovered that electric fields have a major effect on ultracold-atom–cold-molecule collisions. Even though electric fields affect only the orientations of the molecules, they increase the likelihood that a given atom-molecule collision will change the quantum state of the ND3 molecule. And, collisions occurred faster than expected.



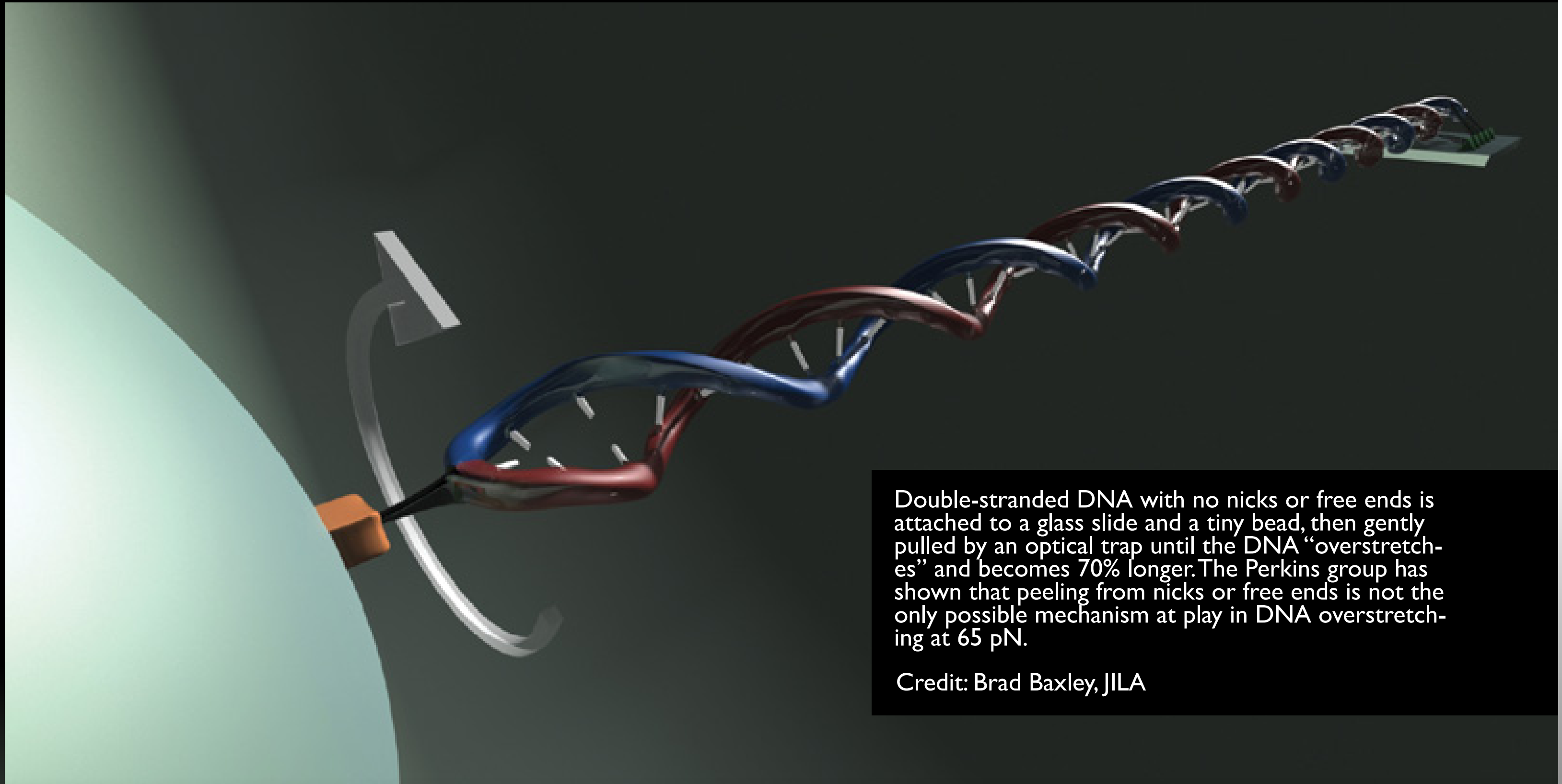
Ultracold atom-cold molecule collisions. (top panel) According to theory, in the absence of an electric field, ND3 molecules will be mostly unaffected by collisions. (bottom panel) Experimentally, electric fields increase the likelihood that collisions will cause an ND3 molecule to flip inside out and change its quantum state. Credit: Brad Baxley, JILA

The JILA researchers enlisted the help of theorist colleagues from the University of Durham (UK) to explain what was happening. New theory showed that electric fields strongly influence atom-molecule collisions — even if there are no dipole-dipole interactions. Dipole-dipole interactions occur between atoms or molecules that have slight differences in charge or magnetic field between one end and the other, resulting in an attraction between ends with opposite polarity. Such dipole-dipole interactions in ultracold quantum gases of potassium-rubidium (KRb) molecules have recently been a hot topic at JILA (See "Quantum Control Room," *JILA Light & Matter*, Winter/Spring 2011.)

However, an entirely different process is at work in the ultracold-atom–cold-molecule collisions studied by the Lewandowski group. In collisions that occur without an electric field, the pyramidal structure of the ND3 molecule is fairly stable. There is only a low probability that a collision will cause the pyramidal structure to flip inside out, i.e., change into a lower-energy quantum state. In contrast, when an electric field is present, the orientation of the ND3 molecule can get "confused" by competing forces that arise as an atom approaches. This confusion increases the probability of a state-changing collision.

Reference:

L. P. Parazzoli, N. J. Fitch, P. S. Zuchowski, J. M. Hutson, and H. J. Lewandowski, *Physical Review Letters* **106**, 193201 (2011).



Double-stranded DNA with no nicks or free ends is attached to a glass slide and a tiny bead, then gently pulled by an optical trap until the DNA "overstretches" and becomes 70% longer. The Perkins group has shown that peeling from nicks or free ends is not the only possible mechanism at play in DNA overstretching at 65 pN.

Credit: Brad Baxley, JILA

Upending Conventional Wisdom

JILA experiment shows nicks and free ends are not required for DNA overstretching

In science, it can be fun and interesting to upend conventional wisdom. A good example is what just happened to a widely accepted explanation for overstretching of double-stranded DNA (dsDNA). Overstretching occurs suddenly when researchers add a tiny increment of force to dsDNA that is already experiencing a pulling force of approximately 65 pN. (A piconewton is a trillionth of a newton, which is roughly equal to the gravitational force on a medium-sized apple). The small additional force causes the dsDNA to suddenly become 70% longer — as it stretches like a slinky.

The mechanism for such DNA overstretching has been the subject of active debate for the last 15 years. In 2009, however, most biophysicists were sure that a Dutch group had finally done the definitive experiment: They saw that the extra force caused single strands of DNA to peel apart starting from either broken bonds in the DNA backbone (nicks) or loose-hanging single DNA strands (free ends). In fact, researchers from Northeastern University and the University of Minnesota declared this work the "smoking gun," and the matter was settled; the mechanism of overstretching was force-induced peeling from free ends or nicks.

Recently, however, research associate Hern Paik and Fellow Tom Perkins began to wonder what would happen to dsDNA in an overstretching experiment if it didn't have any nicks or free ends. Paik devised an elegant experiment in which he could make a sample with no nicks or free ends, but still leave the DNA free to twirl around. To allow for this rotation, he attached a small loop of DNA to a longer DNA molecule. Importantly, the loop contained a single chemical group that the researchers used to attach the loop to a bead that could be pulled by an optical trap. The resulting single attachment allowed rotation of the DNA with respect to the bead. Paik fastened the other end of the DNA via both its strands to the surface of a glass slide, a geometry that eliminated any free ends.

In a series of carefully constructed overstretching experiments, Paik found that when he tugged on this dsDNA at 65 pN, it still increased in length by 70% — even though it contained no nicks or free ends. The new experiment showed the smoking gun wasn't conclusive after all. Clearly, the sole mechanvDNA overstretching is not peeling. The challenge now is to explain why dsDNA that lacks nicks or free ends overstretches at the same force implicated in force-induced peeling.

"Our data, in conjunction with prior work, suggest that there are two distinct structures produced by overstretching dsDNA," says Perkins. "Since the two structures appear to have similar mechanical properties, they may lie at the root of this controversy."

One structure is the peeled DNA seen by the Dutch group. The big question now is: what is the other structure? It may be molten DNA, or M-DNA. M-DNA would be created if dsDNA internally melts into a pair of parallel ssDNA during overstretching. This mechanism would not require nicks or free ends. Another possibility is that a new form of dsDNA, called S-DNA, appears during overstretching. In S-DNA, the base pairs would remain intact, but the DNA double helix would unwind into a straight ladderlike structure that is approximately 70% longer than the classic double-helix structure of dsDNA.

Paik and Perkins are now working to better understand what actually happens during overstretching. They want to see how temperature, acidity, and salt concentrations affect overstretching and thereby determine if overstretched DNA (without nicks) forms via M-DNA or S-DNA. Their goal is a deeper understanding of the science of DNA overstretching. This understanding will be invaluable for the development of DNA as a standard for forces between 0.1 and 100 pN (See *JILA Light & Matter*, Winter 2008).

Reference:

D. Hern Paik and Thomas T. Perkins, *Journal of the American Chemical Society* **133**, 3219–3221 (2011). [Cover article].

THE WORLD ACCORDING TO COS

The Cosmic Origins Spectrograph, or COS, is a powerful new instrument scanning the Universe. COS was installed on the Hubble Space Telescope in 2009. Since then, it has been searching for clues about the composition of the Universe, including how galaxies like our own Milky Way formed and evolved over time. It is seeing beautiful things never before detected in the Universe because it is the lowest-noise ultraviolet (UV) spectrograph ever built for space exploration.

The instrument was designed at the University of Colorado at Boulder (UCB) and built by Ball Aerospace & Technologies Corp. of Boulder. JILA Fellow Jeff Linsky helped design the instrument and is a member of the COS science team. He is now reaping the benefits of the instrument's ability to extract meaningful signals from what was just instrument noise on earlier space-borne UV spectrographs. With the help of collaborators including research associate Hao Yang, undergraduate student Rachel Bushinsky, and Kevin France of UCB's Center for Astrophysics and Space Science, Linsky is analyzing COS data from young suns with protoplanetary disks of gas and dust in the process of forming planets.

In young binary star systems, for example, the researchers identified evidence of molecular hydrogen (H_2) being excited by radiation from their stars. H_2 molecules are major constituents of protoplanetary disks. They are impossible to detect unless their electrons are being excited to higher electronic states or returning to lower states by emitting UV light. Although other observatories have detected the energetic UV fluorescence from H_2 molecules, COS is the first instrument to find evidence of the stars themselves exciting, or "pumping," the H_2 molecules. The evidence consists of weak absorption lines seen against the bright atomic-hydrogen Lyman-alpha emission lines from the stars.

From the absorption in the pumping lines created by newly excited H_2 molecules, the researchers were able to compare absorbed energy with the energy emitted by UV fluorescence. They discovered that energy was missing at certain wavelengths and concluded they were observing UV emission through the accretion flow from the disk onto the stars.

In a related study, Linsky, Yang, France, and colleagues from the United States and Europe found the first evidence of carbon monoxide (CO) in far UV spectra of the inner regions of protoplanetary disks of three stars. CO is one of the simplest molecular building blocks of planets. "This work represents the first steps in empirically determining the chemical composition of the protoplanetary disk where planets will form," Linsky says. "Being able to measure the amount of both CO and H_2 is important in determining the composition and evolution of planetary atmospheres."

COS sits inside the Orbital Replacement Unit Carrier prior to installation on Hubble Space Telescope in 2009. COS has restored UV spectroscopy to Hubble's scientific arsenal. Credit: NASA

Linsky's analysis of CO and H_2 in the very young star systems indicates that protoplanetary disks are made of very primitive material. For example, the ratio of CO to H_2 in the inner part of these disks is approximately 1. This value represents a transition between the much lower value found in the interstellar medium and the higher value found in solar system comets, which formed from a similar disk more than four billion years ago.

In a third COS study, Linsky, France, and colleagues from UCB analyzed UV emissions from solar-type stars, some younger than the Sun and some older. Their goal was to learn more about the far-UV emissions from the young Sun and how such emissions affected the young Earth's atmospheric chemistry. The researchers focused on the COS instrument's first-ever measurements of the far UV continuum emission produced by magnetically heated gas in the outer layers of the stellar atmospheres. Before COS, this faint continuum emission could not be detected between the stars' bright emission lines. The researchers found that the continuum emission from young, rapidly rotating stars was more intense than that from older, more slowly rotating stars like the Sun. However, the continuum emission from the young stars was similar to what is seen in regions of the Sun with strong magnetic fields.

By using the Sun as a "Rosetta Stone," the scientists were able to deduce that the young Sun (like the young stars observed by COS) was once covered with very strong magnetic fields. Today, only weak remnants of these fields remain in the Sun and other older stars.

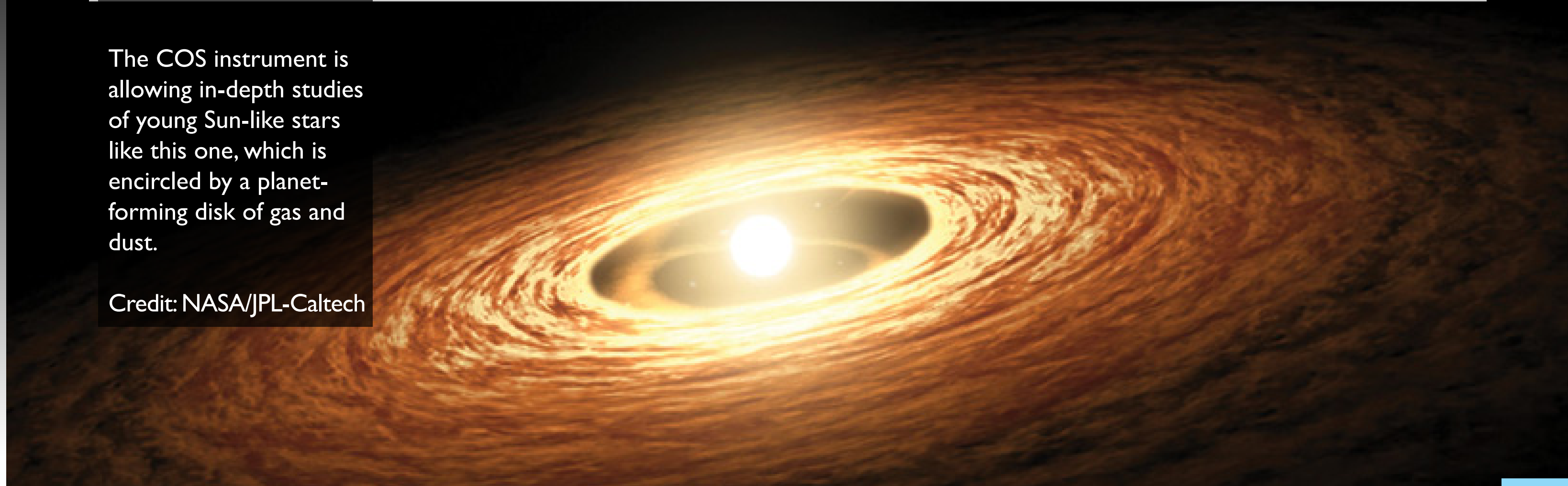
"Thanks to COS, my group is now doing stellar archaeology," Linsky says.

References:

Hao Yang, Jeffrey L. Linsky, and Kevin France, *The Astrophysical Journal Letters* **730**, L10 (2011).

Jeffrey L. Linsky, Rachel Bushinsky, Tom Ayres, Juan Fontenla, and Kevin France, *The Astrophysical Journal Letters*, submitted.

Kevin France et al., *The Astrophysical Journal* **734**, 31 (2011).



The COS instrument is allowing in-depth studies of young Sun-like stars like this one, which is encircled by a planet-forming disk of gas and dust.

Credit: NASA/JPL-Caltech

QUANTUM CT SCANS

They see only their own shadows or the shadows of one another, which the fire throws on the opposite wall of the cave — Plato

The Lehnert group and collaborators from the National Institute of Standards and Technology (NIST) recently made what was essentially a CT scan of the quantum state of a microwave field. The researchers made 35 measurements at different angles of this quantum state as it was wiggling around. During the measurements, they were able to circumvent quantum uncertainties (in a process known as squeezing) to make virtually noiseless measurements of amplitude changes in their tiny microwave signals. Multiple precision measurements of the same quantum state yielded a full quantum picture of the microwave field.

"What we did was a quantum version of the CT scan for light at microwave frequencies," says Lehnert. "Since we can represent information as a state of a microwave field, this is a lively topic in the field of quantum information processing." Lehnert adds that measuring microwave fields (and manipulating information with them) already works fairly well with microwaves trapped inside a box, or cavity. However, the Lehnert group and its NIST collaborators have taken the plunge of measuring a single quantum state outside the box.

The JILA team includes research associate François Mallet, graduate student Hsiang-Sheng Ku, former graduate student Manuel Castellanos-Beltran, and Fellow Konrad Lehnert. Their NIST-Boulder collaborators include Scott Glancy, Emanuel Knill, Kent Irwin, Gene Hilton, and Leila Vale. The eventual goal of the joint research is the creation of quantum entanglement of different quantum states of a microwave field outside of a cavity. Quantum entanglement is a kind of spooky shared quantum state (superposition) that extends across space and time. It is an essential ingredient for high-speed quantum computing.

The key ingredient in creating quantum entanglement as well as in measuring the quantum state of a microwave field is a Josephson parametric amplifier, or JPA. The best-ever design of such a device was created in 2008 by the JILA/NIST collaboration. This JPA not only functioned as a virtually noiseless amplifier (See JILA Light & Matter, Fall 2008), but also had ability to squeeze most of the quantum fluctuations (wiggles) out of one of the two directions of a coordinate system.

In their recent experiment, the researchers used one JPA as a preamplifier to improve the quantum efficiency of their measurement from 2 to 36% and the other to squeeze the microwave field. In the squeezed direction, the measured field change was as low as 40% of the amount of quantum fluctuation that normally occurs in a vacuum. In other words, this JPA works better in one direction than even Mother Nature does. The result of all this quantum precision is a full tomographic image of a single state of a microwave field.

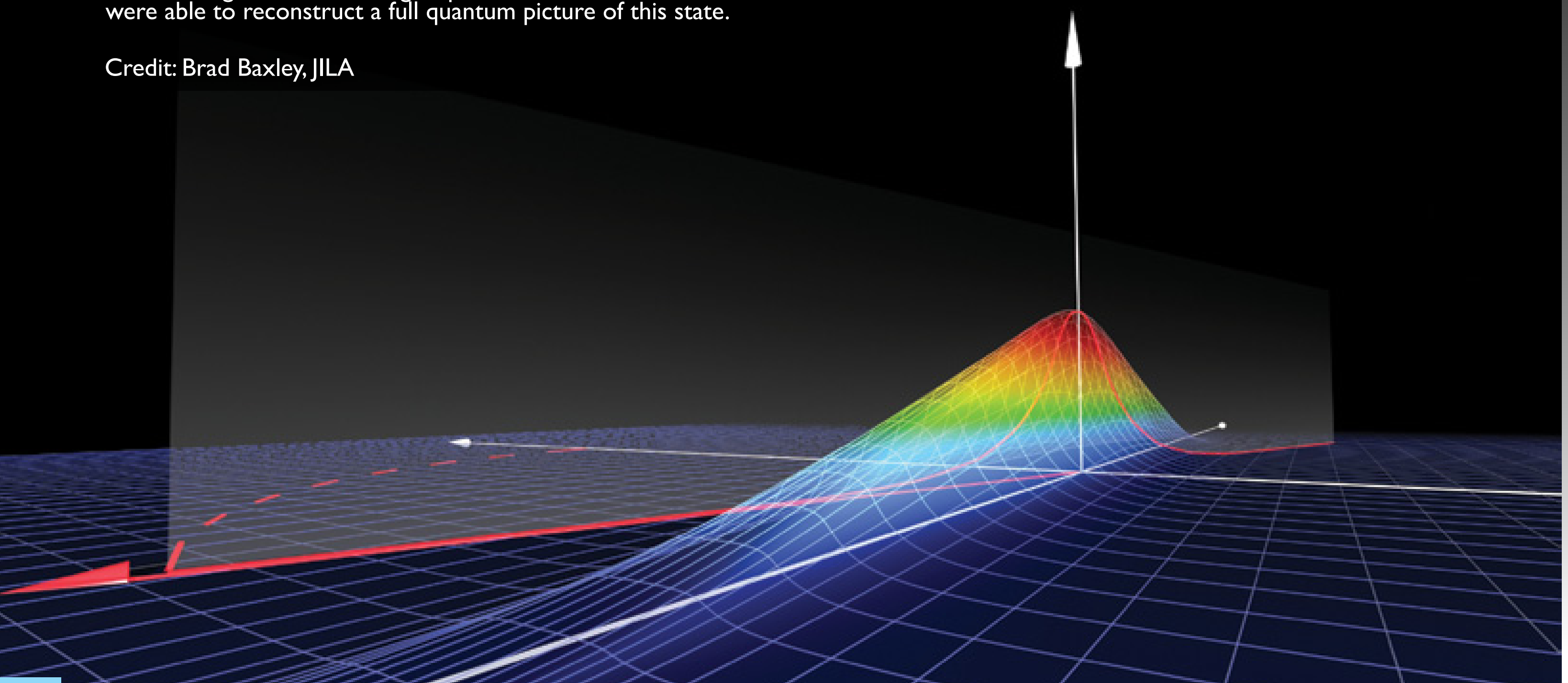
With results like these, the collaboration is ready to explore what happens when they use four JPAs to create two microwave squeezed states at the same time and then combine the squeezed states in a beam splitter. The researchers are already beginning to imagine the creation of millions of bits of entanglement every second. At this rate, the new quantum CT scan could soon seem like child's play.

Reference:

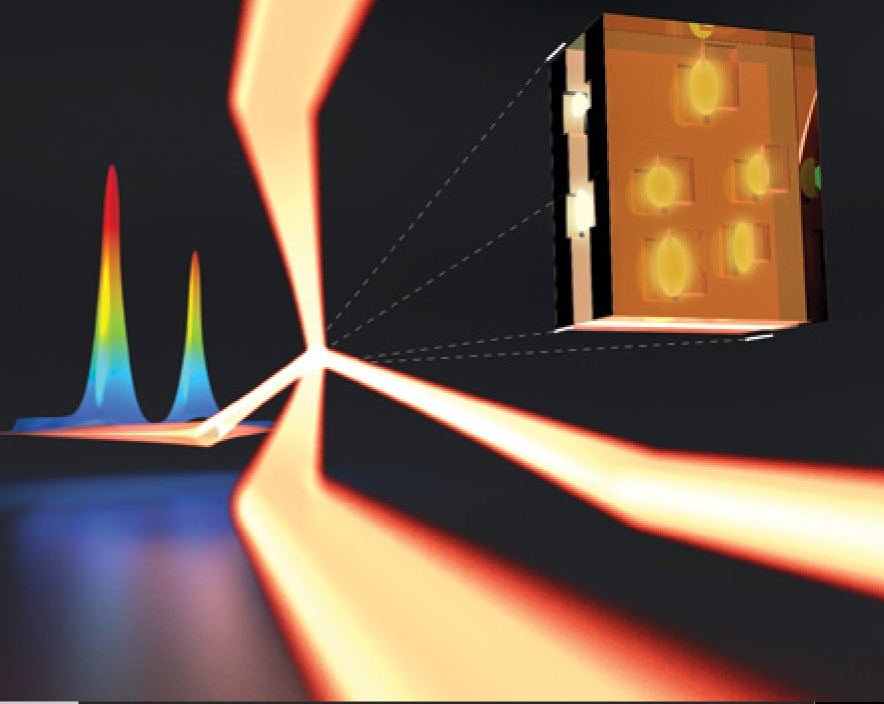
F. Mallet, M. A. Castellanos-Beltran, H. S. Ku, S. Glancy, E. Knill, K. D. Irwin, G. C. Hilton, L. R. Vale, and K. W. Lehnert, *Physical Review Letters* **106**, 220502 (2011).

Image showing location and densities of a single quantum state of a microwave field. By taking slices through this state at 35 different angles, the Lehnert group and its NIST collaborators were able to reconstruct a full quantum picture of this state.

Credit: Brad Baxley, JILA



JILA MONSTR and the CHAMBER OF SECRETS



A series of three laser pulses from the JILA MONSTR interacts with tiny boxes (called quantum dots) of gallium arsenide, a semiconductor material. The combined signal that emerges from the boxes contains information about the quantum interactions of the particles inside the boxes. Credit: Brad Baxley, JILA

The semiconductor gallium arsenide (GaAs) is used to make tiny structures in electronic devices such as integrated circuits, light-emitting diodes, laser diodes, and solar cells that directly convert light into electrical energy. Because of GaAs's importance to modern electronics, the Cundiff group seeks to understand the fundamental physics of its light-matter interactions on atomic and subatomic levels. Such an understanding requires the ability to "look" inside tiny boxes of GaAs (called quantum dots) with a series of laser pulses and correctly interpret the pattern of frequencies produced by the interaction of laser light with particles in the boxes. However, opening up these quantum "chambers of secrets" is a major challenge.

Fortunately, peering into quantum dots is the perfect job for the JILA MONSTR! The MONSTR is a precision optics instrument containing three cascaded and folded interferometers that split incoming laser pulses into four identical pulses. The sequence and spacing of three of the pulses can be controlled to probe the GaAs quantum dots. The process is akin to striking a bell with a hammer three times: The first strike makes the bell vibrate. The second creates an interference pattern in the original vibration, enhancing some frequencies and damping out others. The third interacts with the remaining frequencies and the resulting ring-tone pattern contains information about the dynamics of the bell.

Similarly, the signals produced by interactions with a series of laser pulses reveal information about the dynamics of the strange world inside the GaAs quantum dots. When particles there interact with one or more pulses of laser light, they radiate light of different colors (frequencies). Researchers use a spectrometer and computer to convert these signals into multidimensional frequency spectra that make it easier for them to look for evidence of particle interactions.

Recently a team led by graduate student Galan Moody used the MONSTR to not only learn more about GaAs quantum dots, but also the interactions of particles inside the dots with the GaAs quantum well that surrounds them. The experimenters used samples arranged like Oreo™ cookies: The cookies correspond to the sample holder, the filling corresponds to a two-dimensional quantum well, and lumpy "islands" in the filling correspond to the zero-dimensional GaAs quantum dots. Inside both quantum dots and the quantum well, the laws of quantum mechanics determine behavior of atomic and subatomic particles.

Gaining a better understanding of how those laws affect the behavior of particles in the quantum dots was one goal of Moody's experiments. Moody was assisted by former research associates Mark Siemens, Alan Bristow, Xingcan Dai, and Denis Karaiskaj; researchers from the Naval Research Laboratory, and Fellow Steve Cundiff.

The researchers studied excitons both inside the quantum dots and in the surrounding quantum well. An exciton is an atom-like particle consisting of a free electron bound to the positively charged hole that an electron leaves behind when it is excited in a semiconductor. The observed excitons were not as strongly held within the quantum dots as had been predicted. They existed in both bright and dark states and could switch back and forth.

If excitons formed inside a quantum dot, they tended to stay there rather than move into the quantum well. There appeared to be stronger interactions between excitons in quantum dots and the quantum well at lower temperatures. However, at higher temperatures, interactions between the excitons and the vibrating GaAs crystal structure caused the excitons to actually move between the quantum dots and the quantum well.

The researchers studied the behavior of excitons in superpositions of their ground and excited energy states. Such superpositions appear only in the quantum world. They occur when one or more quantized particles (which exist as waves) completely overlap. Over time, the researchers observed that exciton superpositions in the GaAs quantum dots gradually decay back to their ground states. The decay rate was influenced by interactions between the excitons and vibrations in the GaAs crystal structure.

One interesting observations was that sometimes two excitons inside the same quantum dot would hook up to form molecule-like biexcitons. The formation of biexcitons was more likely to occur in smaller quantum dots because the strength of exciton-exciton interactions increases with decreasing quantum-dot size.

The information about GaAs quantum dots garnered by Moody and his colleagues caught the attention of the Physical Review B editors, who picked their journal about this topic as an "Editor's Suggestion" in the March 23, 2011, issue.

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G. Moody, M. E. Siemens, A. D. Bristow, X. Dai, D. Karaiskaj, A. S. Bracker, D. Gammon, and S. T. Cundiff, *Physical Review B* **83**, 115324 (2011).

G. Moody, M. E. Siemens, A. D. Bristow, X. Dai, A. S. Bracker, D. Gammon, and S. T. Cundiff, *Physical Review B*, submitted.

JILA STAFF HIKE 2011

Photography: J.R. Raith, JILA

Kudos to...

Gwen Dickinson for being awarded a JILA PRA Exemplary Contribution Award for her significant contribution to the JILA beautification project.

Chris Greene for being named a College Professor of Distinction by the University of Colorado at Boulder's College of Arts & Sciences.

Jim McKown for being awarded a JILA PRA Exemplary Contribution Award for providing critical leadership in bringing the new JILIAC computer cluster to JILA.

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