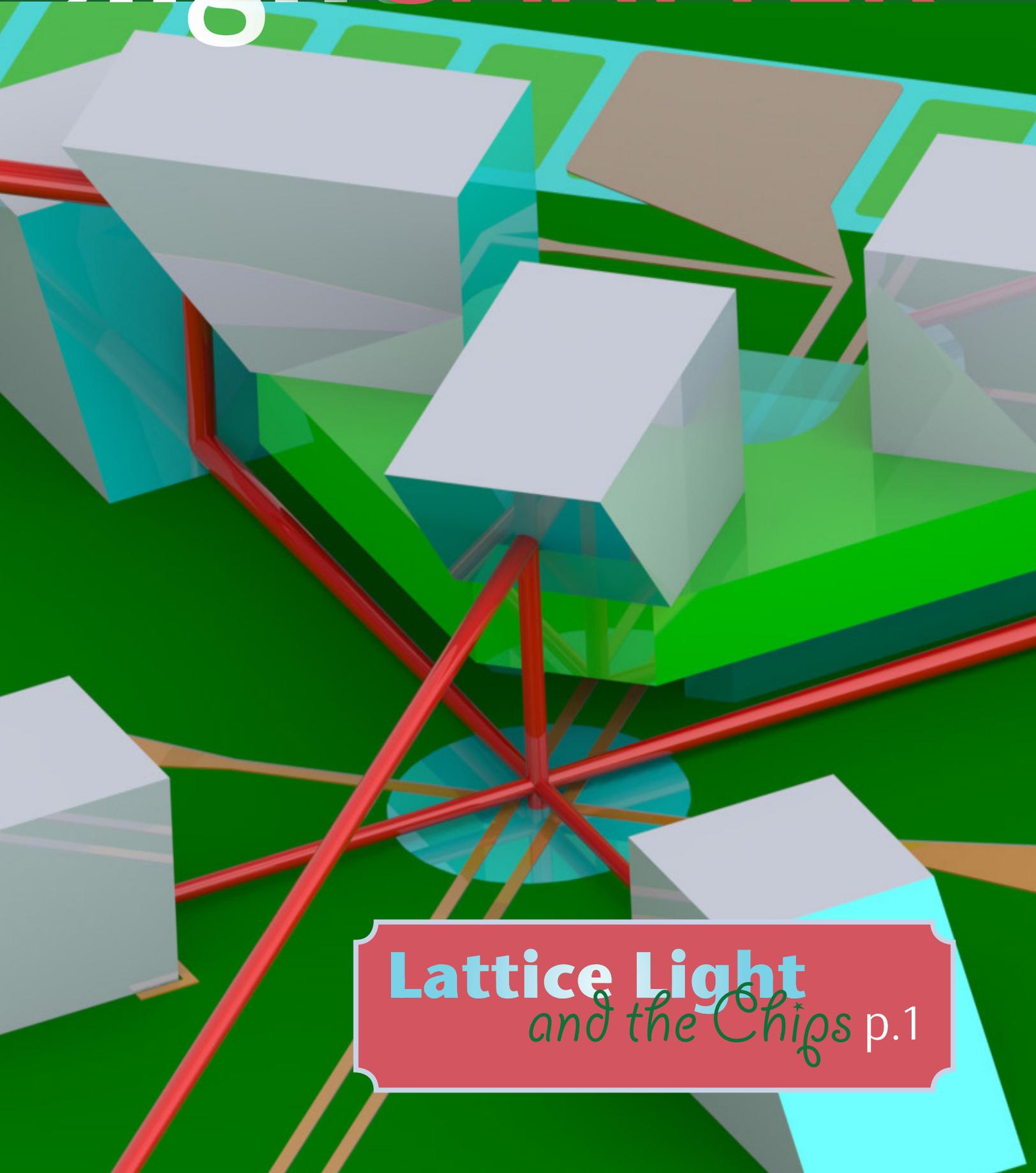


# light & MATTER



**Lattice Light**  
*and the Chips* p.1



A nice spot for contemplation on the University of Colorado Boulder campus. Credit: Kristin Conrad, JILA

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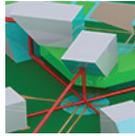
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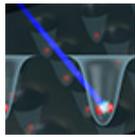
# Stories



Lattice Light and the Chips ..... **1**



Interstellar Meatballs with Spaghetti Inside ..... **3**



An Array of Possibilities ..... **7**



Beautiful & Twisted ..... **9**

# Features

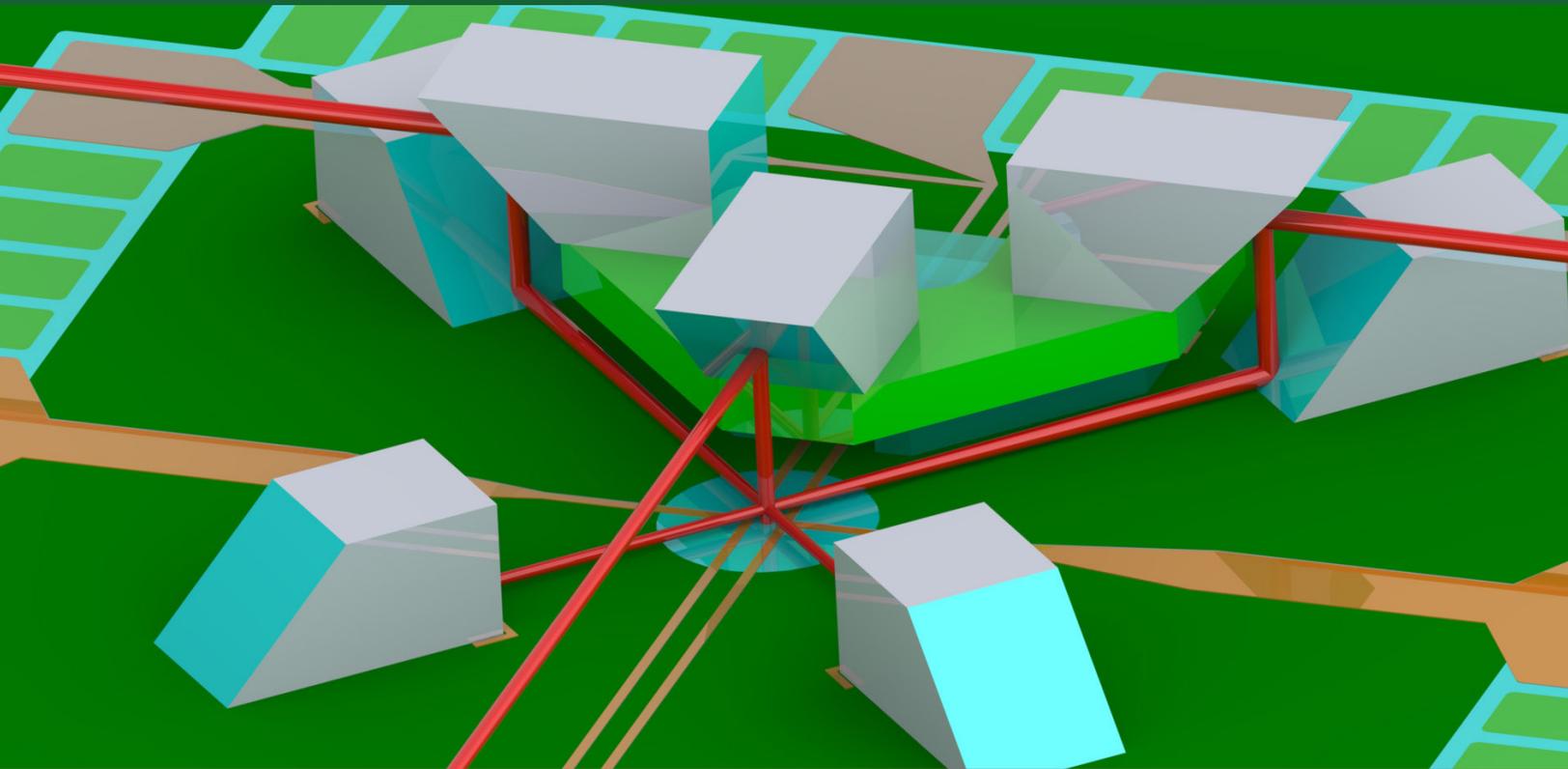
Puzzle: JILA Maze ..... **5**

New Cold Chemistry Conference ..... **11**

Twitter Helps Out the Lehnert Lab ..... **13**

In the News ..... **14**

How Did They Get Here? ..... **15**



Model of the mirrors and light pathways of the on-chip optical lattice. Credit: Cameron Straatsma and the Anderson group, JILA, and ColdQuanta

# Lattice Light *and the Chips*

**C**ompact and transportable optical lattices are coming soon to a laboratory near you, thanks to the Anderson group and its spin-off company, ColdQuanta. A new robust on-chip lattice system (which measures 2.3 cm on a side) is now commercially available. The chip comes with a miniature vacuum system, lasers, and mounting platform.

Graduate student Cameron Straatsma and his colleagues recently completed a successful proof-of-principle experiment with the on-chip optical lattice system. Their goal was to ensure that the miniature lattice system performs as well as typical laboratory-sized systems. The researchers included Megan Ivory, Janet Duggan (former undergraduate student in the Anderson group), Jaime Ramirez-Serrano, and JILA Ph.D. Evan Salim of ColdQuanta as well as Fellow Dana Anderson.

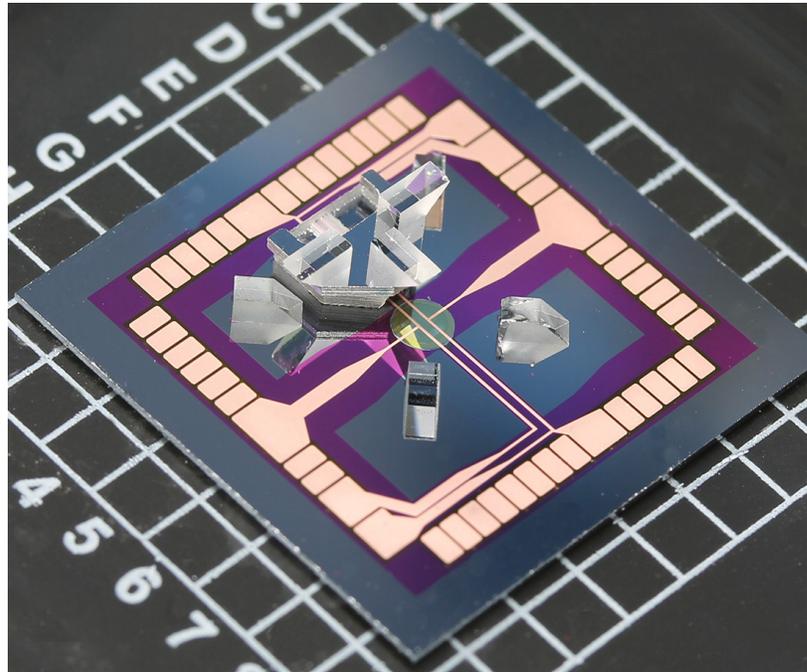
In the experiment at JILA, the Anderson group created a one-dimensional (1D) lattice with a laser beam reflected off the atom chip. The lattice was created by pin-head-sized mirrors directly bonded to the atom chip (at ColdQuanta).

As soon as the on-chip 1D lattice was ready, the investigators placed a tiny Bose-Einstein condensate (BEC) of rubidium atoms in the 1D lattice. The BEC was produced right on the chip!

The researchers soon observed atoms escaping from the on-chip 1D lattice via quantum tunneling, which is a signal that the miniature lattice was functioning properly. The researchers also determined that the optical-lattice atom-chip technology could be readily extended to higher-dimensional optical lattices.

This work may lead to such practical instruments as advanced guidance systems for aircraft, small and transportable atomic clocks, magnetic-field sensors, and innovative laboratory studies of the interactions of atomic spins and motion. On-chip optical lattices could even evolve to become part of plug-in components of tomorrow's quantum computers.

An optical lattice on an atom chip may also be installed on later versions of the Cold Atom Laboratory (CAL), which is being built for NASA's Jet Propulsion Laboratory. CAL is scheduled for deployment to the International Space Station in 2017. Once in space, CAL will be used for ultracold-atom experiments in near-zero gravity.



Photograph of the on-chip optical lattice system. Credit: ColdQuanta

Cameron J. E. Straatsma, Megan K. Ivory, Janet Duggan, Jaime Ramirez-Serrano, Dana Z. Anderson, and Evan A. Salim, *Optics Letters* **40**, 3368–3371 (2015).



The tidal disruption of a star by a supermassive black hole creates a stream of star stuff that looks like a strand of spaghetti stretching from the star to the black hole. The star's self-gravity causes lumps of star stuff to form inside the stream. Credit: The Begelman group and Steve Burrows, JILA

# Interstellar Spaghetti, with Meatballs Inside

## *The upshot of meandering by a supermassive black hole*

When an ordinary star like our Sun wanders very close to a supermassive black hole, it's very bad news for the star. The immense gravitational pull of the black hole overcomes the forces of gravity holding the star together and literally pulls the star apart. Over time, the black hole swallows half of the star stuff, while the other half escapes into the interstellar medium. This destructive encounter between a supermassive black hole and a star is known as a tidal disruption event.

The idea of doing a detailed simulation of a tidal disruption event recently captured the imaginations of graduate student Eric Coughlin and research associate Chris Nixon (Begelman group). Others had done this kind of work, but either with such low resolution that it wasn't possible to see what was happening in the star or with unphysical parameters such as modeling a supermassive black hole as having the mass of 1000 suns when realistically it would have a mass of around 1,000,000 suns.

"We wanted to see exactly what happens if you have a star that's wandering around and finds itself on a path that's going to bring it very close to a supermassive black hole like the one at the center of our Galaxy," Coughlin said, adding that he and Nixon wanted to see what was happening to all the parts of the star during a tidal-disruption process. To do this, the researchers had to create a realistic simulation that used as many physical parameters as possible. They also had to make sure their wandering star didn't get close enough to their simulated supermassive giant black hole to be swallowed whole.

Coughlin and Nixon's simulation followed the tidal disruption encounter for 10 years. They already knew tidal disruption was a gradual process, and they wanted to learn more about how a spherical star gets turned into a stream of star stuff rather like a strand of cooked spaghetti.

"What we found was really surprising," Coughlin said. "About a month after the disruption, portions of the stream started to fragment. It sort of broke up into individual fragments and formed localized gravitationally bound clumps."

In other words, meatball-like globs of star stuff appeared inside (rather than on top of) the spaghetti strand formed by the tidal disruption. The self-gravity of the stream (left over from the star's self-gravity) was creating these "meatballs." Inside the stream, the star particles were both attracted to each other as well as to the black hole that was pulling the whole stream into it. The discovery of the lumps of star stuff has complicated things considerably.

Intriguingly, about an hour after the star's disruption, the researchers observed the front and back of the star start to compress and attempt to switch places. This squeezing, caused by the gravitational field of the black hole, increases the stellar stream's self-gravity and causes the stream to fragment—cooking the meatballs for the black hole to eat. This weird result led the researchers to perform more complex simulations (in collaboration with Fellows Mitch Begelman and Phil Armitage) to test whether the compression is real or just an artifact of the original simulation. Early results suggest there's something really interesting happening.

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Eric R. Coughlin and Chris Nixon, *The Astrophysical Journal Letters* **808**, L11 (2015).

# JILA Maze

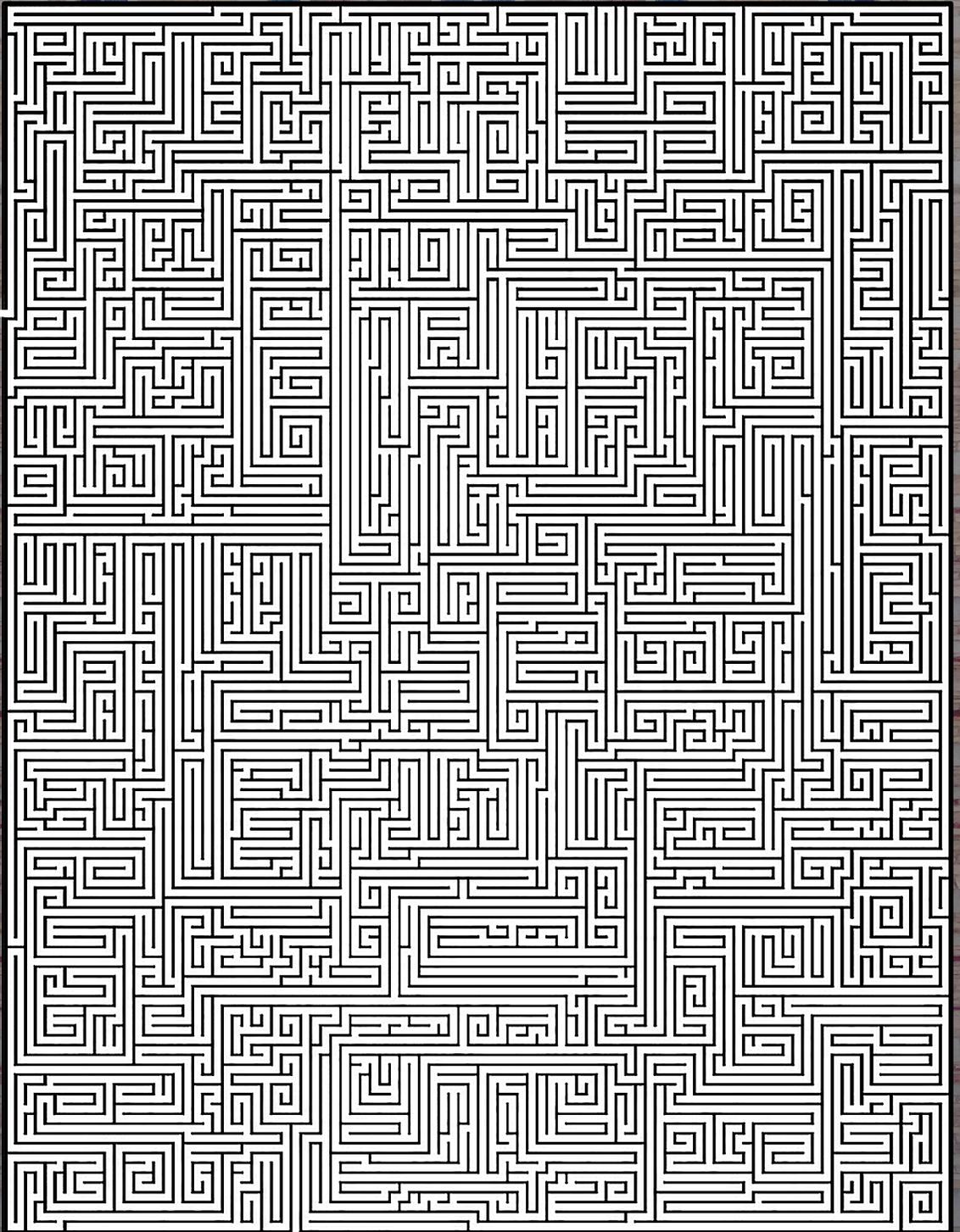
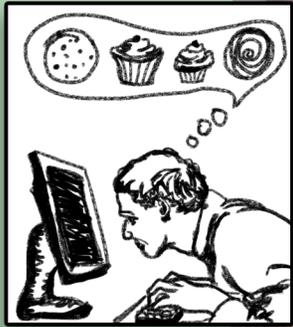
Instructions: Help the hungry JILAn get to “snack time” before the cupcakes are gone. The first person to turn in a correct puzzle to Kristin Conrad (S264) or Julie Phillips (S211) will win a \$25 gift card.

Winning entries can be submitted either in the printed JILA Light & Matter or on the B/W copies mentioned below.

Helpful tips:

1. Use a pencil and color in the pathway. It is too difficult to see the path if you just draw a line.
2. You can download and print extra B/W copies to work on here: [https://jila.colorado.edu/members/sites/default/files/lm\\_fall2015\\_puzzle.pdf](https://jila.colorado.edu/members/sites/default/files/lm_fall2015_puzzle.pdf)
3. It's not “broken”. There is a solution!

*Congratulations to Tara Drake, Rabin Paudel, and Roman Chapurin (Jin group), co-winners of the \$25 gift card for solving the Summer 2015 “Spot the Differences” puzzle.*



JILA snack time!

# An Array of Possibilities

Some assembly required

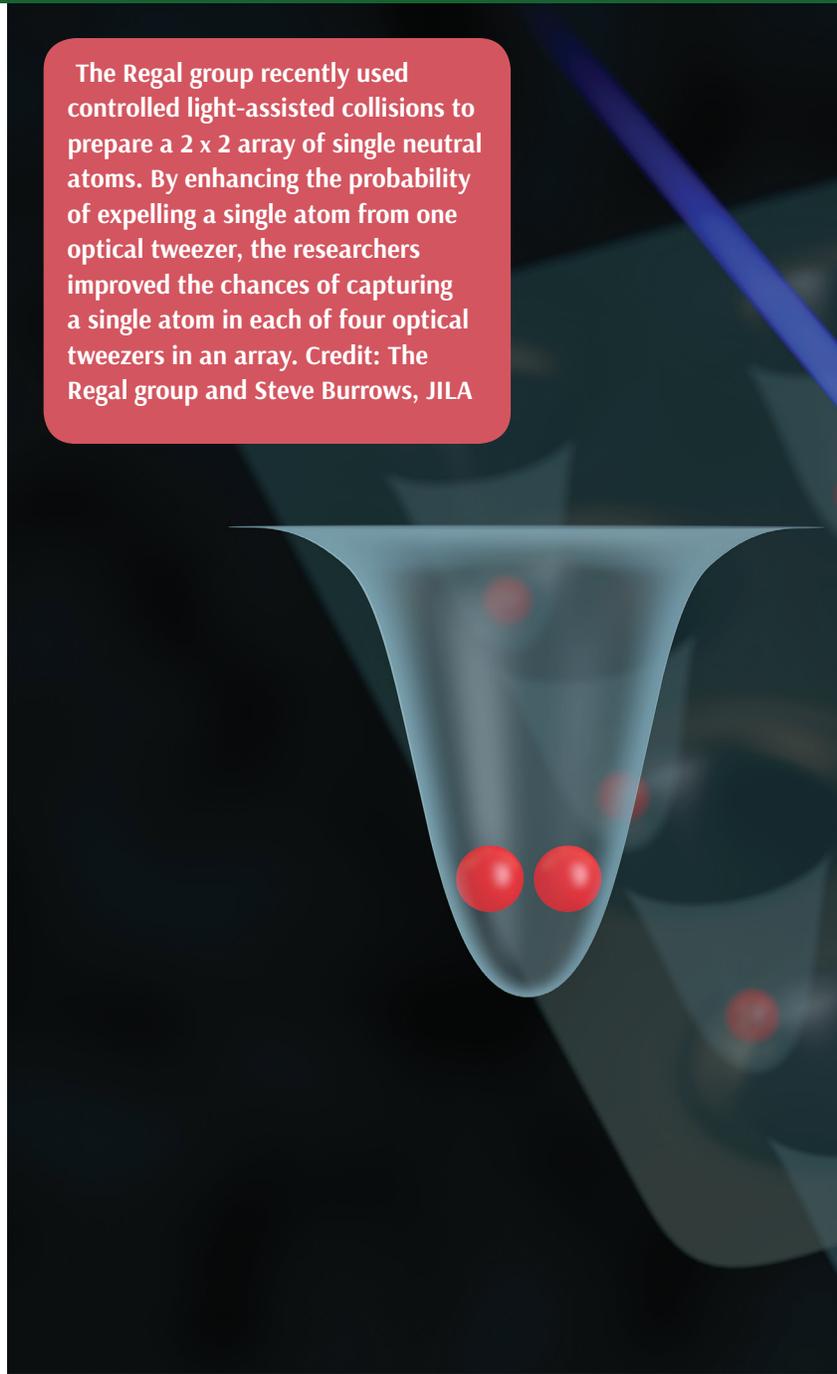
**G**raduate student Brian Lester of the Regal group has taken an important step toward building larger, more complex systems from single-atom building blocks.

His accomplishment opens the door to advances in neutral-atom quantum computing, investigations of the interplay of spin and motion as well as the synthesis of novel single molecules from different atoms.

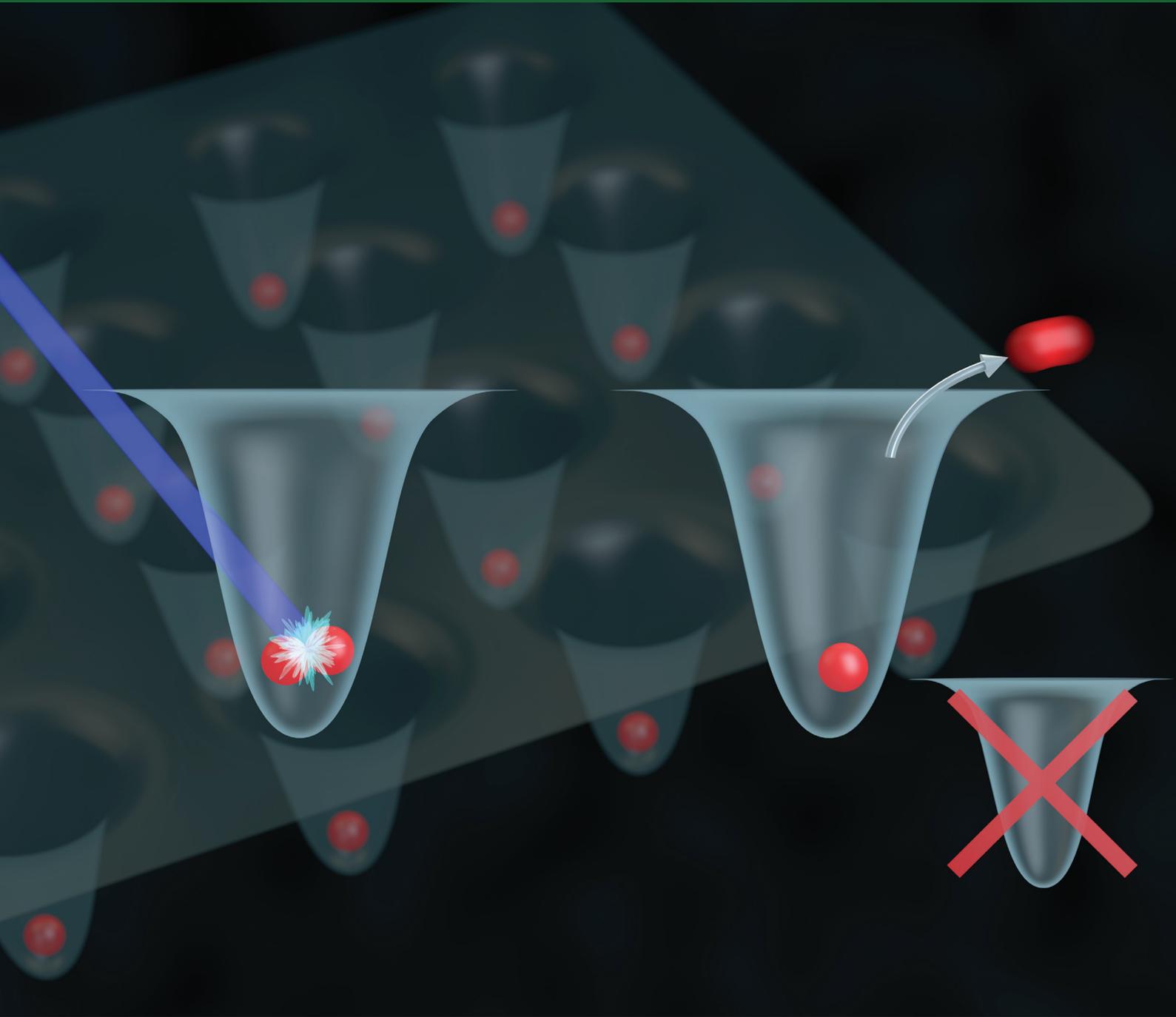
What Lester did was to create a 2 x 2 array of independent optical tweezers (traps), each containing a single neutral rubidium atom. He had to use some interesting physics to get the new system to work because previously anytime two atoms ended up in a single trap during loading, they would collide, and the energy gained during the collision would knock both atoms out of the trap. If enough atoms entered the trap during each loading cycle, the loss of pairs would result in a single atom remaining in a trap in about 50% of the loading attempts.

Then, researchers in New Zealand showed that, with the right set of experimental conditions, the atom-atom collisions could be used to preferentially remove just one atom from the trap. At JILA, Lester and his colleagues adapted these controlled collisions into an efficient and rapid technique to prepare arrays of atoms. In the process, they discovered precisely how close they could bring the traps together before the multiple traps complicated the process and reduced the efficiency of trap loading. Lester's colleagues included Niclas Luick (Universität Hamburg), newly minted Ph.D. Adam Kaufman (now at Harvard), Collin Reynolds (Seagate Technologies), and Fellow Cindy Regal.

The Regal group recently used controlled light-assisted collisions to prepare a 2 x 2 array of single neutral atoms. By enhancing the probability of expelling a single atom from one optical tweezer, the researchers improved the chances of capturing a single atom in each of four optical tweezers in an array. Credit: The Regal group and Steve Burrows, JILA



The change that Lester implemented to his experiment was adding another set of laser beams to the part of the experiment where the atoms are loaded into the traps. This set-up allowed the researchers to adjust the beams to increase the probability of losing only one atom from each trap. Then, as long as the traps were at least 1.7  $\mu\text{m}$  apart, the new beams made it possible to end up with a single atom per trap 90% of the time.



In more than 60% of the experiments with the new setup, four traps in the  $2 \times 2$  array were filled with a single atom in less than 170 ms. This performance is a significant improvement over previous attempts to fill a small array of independent optical tweezers. With this experiment, the group has also gained a better understanding of the physics involved in assembling quantum matter from single atoms held in individual optical tweezers.

This experiment is an important step to realizing the benefits of using an array of optical tweezers to study larger systems of atoms, including the ability to adjust the traps and assemble different neutral atoms into more complex systems.

Brian J. Lester, Niclas Luick, Adam M. Kaufman, Collin M. Reynolds, and Cindy A. Regal, *Physical Review Letters* **115**, 073003 (2015).

# Beautiful & TWISTED

**E**ver wondered how magnetic pressure alone might be able to maintain the structure of an accretion disk around a black hole in an x-ray binary system? Fellow Mitch Begelman recently gave the idea a lot of thought. And, in the process of working on the idea with Fellow Phil Armitage and Chris Reynolds of the University of Maryland, Begelman came up with a new model for accretion disks around black holes in x-ray binary systems such as the one shown in the picture.

The new model shows how twisted magnetic-field oscillations can maintain accretion disk structures via dynamo action. In fact, magnetic dynamos are able to maintain large-scale magnetic fields and the matter they contain over astronomical time scales. Thus the new model also explains (1) how observed spectral changes in the x-ray region of binary accretion disks are associated with two different disk states and (2) why these accretion disks do not appear to be inherently unstable.

Here's what the new model suggests is happening: The magnetic field in an accretion disk behaves like a rubber band. There's a kind of a stretching effect where the disk transfers spin, or angular momentum, from close to the black hole to farther out. This transfer is important because it allows the close-in matter to fall into the black hole, something it wouldn't be able to do if the disk always spun rapidly.

When the spin-transfer process begins, things appear to become powerfully unstable, and the gas actively jerks around, becoming turbulent

and chaotic. This is when things get complicated because it turns out that the magnetic field isn't completely chaotic. Astrophysicists have known for a long time that the turbulence has a tendency to spontaneously self-organize. Various loops of magnetic field start to reinforce neighboring loops, causing them to get really strong in either a clockwise or counterclockwise direction. Initially, both directions have equal probabilities, but once the amplification process starts it all clicks into a single direction.

## The magnetic field in an accretion disk behaves like a rubber band.

What happens (over and over) is that the magnetic field spontaneously goes in one direction and then pivots and goes in the other direction. This periodic reversal of the mag-

netic field is a signature of a magnetic dynamo. And, since the entire disk becomes dominated by a reversing, twisted magnetic field, the dynamo is able maintain the structure of the accretion disk.

However, any time there is a strong magnetic field in the accretion disk orbiting a black hole, the field "wants" to escape vertically. But, the gas attached to the field acts to keep the magnetic field in place. There's a tendency for the magnetic field to buckle even if it's lying flat with gas pressing down on it.

It turns out that random fluctuations in the magnetic field can cause a little piece of the field to buckle, and the buckle can grow and grow until the magnetic field just bubbles away. Of course, at the same time the old field is disappearing, a new magnetic field is being recreated during on-going transfers of spin to the outer regions of the accretion disk.

Begelman discovered that the production of the magnetic field and its escape are in equilibrium. With his new model it's possible to calculate the strength of the magnetic field at various heights of the disk and figure out the degree to which the escaping field is heating up the gas at different heights.

Interestingly, the twisted magnetic field also gives rise to the x-ray spectral changes characteristic of a black hole in an x-ray binary system. When dense gas (often near the disk center) is heated, what appears is an x-ray spectrum dominated by soft, or longer-wavelength, x-rays. In contrast, when much less dense gas (high up in the disk) is heated, the x-ray spectrum is dominated by hard, or shorter-wavelength, x-ray photons. The disk cyclically transitions between being primarily in one or the other of these two states.

One factor affecting this cyclic process is the flow of mass coming into the disk from the black hole's companion star. As a wave of matter comes in, it thickens the inner region of the disk, dragging in more vertical magnetic field. This process tends to enhance the dynamo effect and heats gas very high up in the disk, producing hard x-rays.

If the accretion disk gets too thick, the central part of the disk collapses because of too much cooling. Consequently, it drags in less magnetic field, weakening the dynamo. The flow of mass into the disk ebbs. But, as soon as the disk can no longer radiate energy, it begins to thicken again. The thicker disk starts collecting more magnetic field, and the cycle begins anew.

If Begelman's new model stands the test of time, it will be a paradigm shift in the way astrophysicists understand the behavior of x-ray binary accretion disks.

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Mitchell C. Begelman, Philip J. Armitage, and Christopher S. Reynolds, *The Astrophysical Journal* **809**, 118 (2015).



Fellows Mitch Begelman and Phil Armitage recently studied how magnetic fields help maintain the structure of accretion disks around black holes in x-ray binaries. X-ray binaries like this one consist of either a neutron star or a black hole paired with a normal star like the Sun. The denser partner pulls material from its companion onto it. This image shows the impact on the interstellar environment of jets and winds expelled from the binary. Credit: X-ray: NASA/CXC/Univ. of Wisconsin-Madison/S. Heinz et al.; Optical: DSS; Radio: CSIRO/ATNF/ATCA

# Cold in July

JILA conference focuses on the future of cold-molecule research



Cold Molecule Conference organizers J. Mathias Weber (l) and Heather Lewandowski (r). Credit: Steve Burrows, JILA



Moderator David Chandler (at the podium) with panelists (l-r) Jeremy Hutson, Michael Tarbutt, Veronica Bierbaum, and Jonathan Weinstein during a lively discussion with members of the audience on “How cold is cold enough?” on July 8 during the *Defining New Directions in Cold Chemical Physics* conference held at JILA. Credit Steve Burrows, JILA

Physicists and chemists from all over the world came to JILA to attend an innovative three-day conference on *Defining New Directions in Cold Chemical Physics* held July 8-10, 2015. The brainchild of Fellows Heather Lewandowski and J. Mathias Weber, the conference brought together AMO physicists and physical chemists to exchange ideas, technologies, and views on important questions in the field of cold-molecule research.

“We thought there was real value in having those two communities talk to each other,” Lewandowski said. “Up to now, they have used different tools and often asked different questions when they

were investigating chemical physics at low temperatures. We thought these two disconnected groups could benefit from talking with each other.”

AMO physicist Lewandowski and chemical physicist Weber had already discovered the benefits of sharing ideas across their own fields at JILA. Earlier in the year, the two had been discussing possible collaborative research projects on cold molecules when Lewandowski came up with the idea for the conference and Weber immediately agreed to help her make it happen.

“Basically, Heather and I got talking,” Weber recalled. “We asked ourselves, ‘Where is this field of cold molecules actually going?’ We saw very different viewpoints coming from AMO physicists and physical chemists. What were people really interested in?” The two scientists decided to bring together experts in physics and chemistry to see if they could come up with interesting approaches to answering the question.

Weber and Lewandowski’s next step was figuring out the structure of the conference. First, they came up with three central questions they wanted to address: (1) How cold is cold enough? (2) What are the opportunities of system complexity for cold chemical physics? and (3) What can we learn from controlling a system?

Second, they featured their three questions in the overview talks and panel discussions that were the central focus of each day of the conference. Their goal was to create the opportunity for researchers to answer these questions from their own unique perspectives.

Finally, they invited talented researchers across all stages of their careers to attend the conference. They wanted a mix of young scientists who



Group photo of scientists attending the *Defining New Directions in Cold Chemical Physics* conference. Credit: Steve Burrows, JILA

were not yet tenured, established researchers, and senior scientists from the United States and overseas. They chose these speakers carefully, opting for people who would be comfortable answering questions from differing viewpoints.

All this planning led to a successful conference that generated interesting ideas and much discussion. People got excited about the possibility of applying AMO physics cold-ion-trap technology to the study of more complex ions, possibly even involving chemical reactions. They also liked the idea of doing spectroscopy on complex molecules inside a really cold environment. Physical chemists were intrigued by the possibility of using frequency comb technology for experiments on ions. For their part, the AMO physicists were astonished to discover that physical chemists were able to bring enormous molecules like proteins and nucleic acids into the gas phase.

"I think we were successful in getting people to talk to each other," Lewandowski said after the

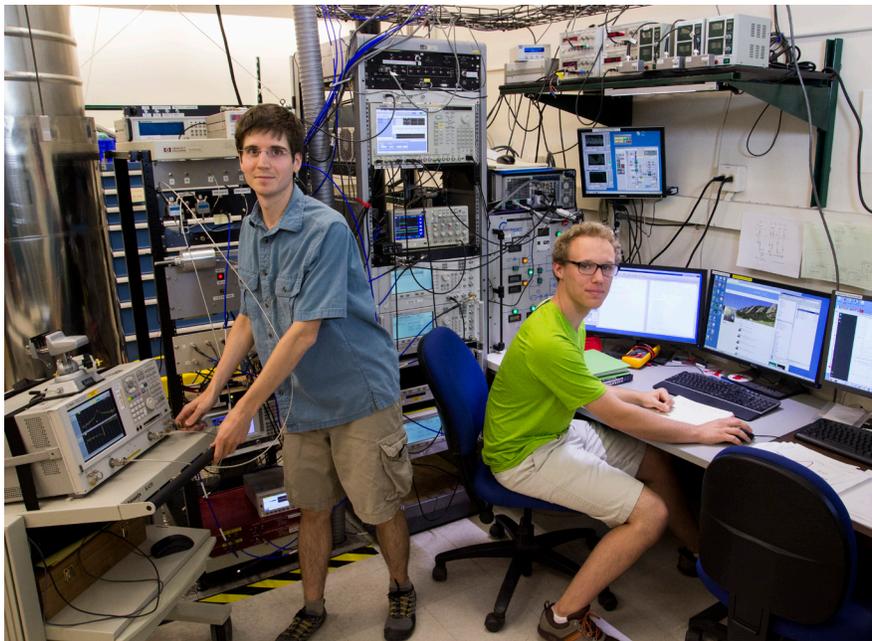
conference. She said more than one attendee came up to her and said something to the effect of, "I can't remember the last time I was engaged through an entire conference. Usually, by the second day, I'm zoned out and hanging out on email. The very last session of the last day, I was engaged and talking to people."

Lewandowski and Weber acknowledged that the answer to the question of where the field of cold molecules is going won't be a simple roadmap. The conference showed a number of intriguing possible directions, and the definition of the field will continue to evolve.

"The discussion at the conference is going to impact my research," Weber said. "Heather and I have been wanting to collaborate for some time now. We bring very different expertise to the table, and we could do something very interesting together." Stay tuned for new cold chemical physics experiments at JILA.

# Twitter Helps Out the Lehnert Lab

Artificial atom experiment sends tweets to avert late-night trips to JILA



Adam Reed (l) and Lucas Sletten (r), Lehnert group. Credit: Steve Burrows, JILA

shut off whenever the compressed air ran out.

“We were having trouble whenever the building compressed air ran out or the experiment’s helium level dropped too low,” Reed explained. “We didn’t want to go away for the weekend and come back and find our experiment in a disastrous state.”

So, when graduate student Sletten joined the Lehnert group, his first project was to set up a Twitter-monitoring system for the artificial-atom experiment. Sletten joined forces with J. R. Raith, one

Adam Reed and Lucas Sletten (Lehnert group) have a good thing going with their experiment to create and characterize an artificial atom: a custom refrigerator and computer system that automatically send a tweet anytime the temperature, pressure, helium level, or other critical parameter changes. Because many problems can be fixed by logging onto the computer controlling the refrigerator, the researchers can often take care of things from home.



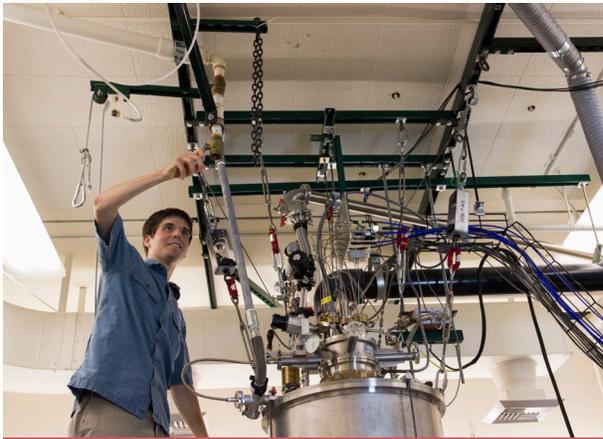
**Dilan @Cryoconcept Oct 23**  
Atom online, ready to go

Reed got the idea of using Twitter from former research associate Michael Schroer, who used it to keep tabs on a different refrigerator that would

of JILA’s resident computer wizards, to make it happen.

Raith and Sletten created a dual computer system with one computer connected to and monitoring the experiment. This computer was not connected to the Internet. However, this computer was connected to another computer that was connected to the Internet. Then, if the first computer generated an error message, it automatically told the computer connected to the Internet. The second computer automatically tweeted the problem.

“This setup allows us to access our experiment on the Internet without being directly connected to the Internet,” Reed said. “That gives us peace of mind. I can be deep in the mountains and can check my cell phone to see if I have any error messages.”



Adam Reed on a ladder adjusting a pressure valve on the custom refrigerator used in the Lehnert Lab's artificial atom experiment. Credit: Steve Burrows, JILA

If error messages show up, Reed or Sletten can log onto the computer connected to the refrigerator and check the status of the experiment. They can make adjustments remotely without having to cut a vacation short.

**Dilan @Cryoconcept Oct 25**  
A222: Helium level too low



It's a good system. When JILA's compressed air system went down in August this year, Reed and Sletten knew immediately via Twitter. They didn't get an email about the problem from Facilities Management until 24 hours later. That delay is long enough to ruin a sensitive experiment.

Is your lab using social media in an innovative way? Tell us about it and we may do a follow-up feature in a future issue of *JILA Light & Matter*. Email [communications@jila.colorado.edu](mailto:communications@jila.colorado.edu).

# IN THE NEWS

## IN THE NEWS?

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

### BEN GREER WINS R. N. THOMAS AWARD

Graduate student Benjamin Greer has won the 2015 R. N. Thomas Award. The \$500 award comes from a fund established by Nora Thomas, the widow of JILA co-founder Dick Thomas. Greer also received a book about Thomas' storied career in astrophysics.

Greer is a fifth-year graduate student in Astrophysical and Planetary Sciences who plans to graduate in December. He works under Fellow Juri Toomre and Senior Research Associate Brad Hindman.

In announcing the award to JILA, Toomre said, "Ben is highly motivated and very independent. He shows a real flair at the interface of theory and computational analysis of complex astrophysical data.

"For his thesis research, he focused on fundamental reassessments of how one can use high-resolution helioseismic observational data to probe solar subsurface flows in detail within the near-surface shear layer. The results are superb."

As first author, Greer has published three papers and is currently preparing two more. Two of Greer's published papers present an important modernization of the local helioseismic technique of ring analysis. In them, he developed improved measurement techniques for flows beneath the surface of the Sun. With them, it is now possible to measure flows twice as deep as previously possible. The spatial resolution of these measurements has also improved threefold.

Toomre says Greer's recent work on analyzing data from the Helioseismic and Magnetic Imager on the Solar Dynamics Observatory may be revolutionary. Greer's new techniques are already influencing the study of subsurface dynamics of the Sun.

# How Did They Get Here?

**Cindy Regal** arrived in early January of 2010 as an Associate Fellow and a University of Colorado Boulder Assistant Professor of Physics. Her experimental physics labs have found a home on the second floor of JILA, and she teaches a variety of undergraduate courses in the physics department.

Three major research efforts are underway in the Regal group. They are providing the group with advanced experimental capabilities in both cold atoms and nanomechanical systems.

The first research effort is the control of single neutral atoms. In this work, the group uses a tightly focused beam of light (called optical tweezers) to confine a single atom of rubidium (Rb) long enough to laser cool it to its lowest-energy state. This experiment has become a source of cold atoms for investigations in quantum optics, quantum simulation, and quantum computing. Laser-cooled ground-state atoms may soon be used in few-atom studies of strongly correlated physics. The group is currently investigating multiple tweezers with tunnel coupling and has started collaborating with the Rey theory group at JILA.

The second research thrust is the investigation of mechanical resonators coupled to optical cavities. In this project, the group is harnessing radiation pressure to deeply cool mechanical motion. This work is expected to open new frontiers in quantum information and the study of quantum limits to measurement. For



instance, in one experiment laser light was used to track the position of a tiny drum, and the researchers observed the quantum backaction in this measurement. More recently, the miniature light-powered machines the group builds have been able to reduce the amount of quantum noise in the amplitude of the light.

The third research effort is a collaboration of the Regal and Lehnert groups. The collaboration's goal is to build a converter that, by harnessing the motion of a tiny drum, can reversibly and efficiently link microwave and optical light. Such a microwave-to-optical converter would be able to link quantum computers via optical fibers, making it possible to build large-scale quantum information networks.

Regal's research interests are creative extensions of her early training that ranged from AMO to devices and condensed matter physics. She did graduate work at JILA with Fellow Debbie Jin on ultracold atoms. As part of her thesis work, she succeeded in getting pairs of fermions to dance together and form a condensate. Her postdoctoral research in the Lehnert lab provided her with new techniques for cooling nanomechanical oscillators with microwaves, a process similar to laser cooling of atoms. At Caltech with Jeff Kimble, she further explored the idea of laser cooling nanomechanical oscillators while also learning about quantum optics and quantum information processing with cold atoms.

Regal has won several prestigious awards, including the University of Colorado Boulder's first Clare Booth Luce Professorship in 2010, the David and Lucille Packard Fellowship for Science and Engineering, and an Office of Naval Research Young Investigator Grant in 2011, as well as a 2012 Presidential Early Career Award in Science and Engineering.

Cindy is originally from Duluth, Minnesota. She is married to former JILAn Scott Papp, who is with the Time and Frequency division at NIST. The couple has a young family, and they enjoy living in Boulder.



## 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.

To learn more about or donate to JILA:  
[jila.colorado.edu](http://jila.colorado.edu).

