JILA: Light & Matter

Special Issue_2011

Paul Arpin, Matt Seaberg, Qing Li, and Jonathas de Paula Siqueira work on developing laser technology in the Kapteyn/Murnane lab.

Credit: Brad Baxley, JILA

Teamwork at JILA

A defining characteristic of JILA is teamwork. Our scientists not only collaborate on pioneering physics research, but also work together to secure and manage major grant funding as well as collaboratively oversee the operations of the Institute. The JILA staff shops, including the Supply Office, are also teamwork operations.

JILA scientists regularly partner with our shop staffs to create exemplary new technologies in support of the Institute's experimental research. The Institute also supports an unusual amount of flexibility and creativity in assembling top-notch research teams to tackle challenging research in atomic, molecular, and optical physics; astrophysics; precision measurement; and other scientific areas.

This special issue of JILA Light & Matter showcases many of the ways in which teamwork enhances JILA's research on the frontiers of physics. We hope you enjoy it.

Exploring the frontiers of quantum mechanics

A More Perfect UNION

JILA's Collaborative Management Style Fosters Excellence

For almost 50 years, JILA has attracted some of the finest research scientists in the world — and kept most of the JILA Fellows here in Boulder despite their having ample opportunities to move elsewhere. JILA's supportive environment for research and collaboration is a result of the National Institute of Standards and Technology (NIST) and the University of Colorado (CU) taking the best aspects of each organization and blending them. As a result, JILA not only fosters ground-breaking scientific research, but also provides exceptional training to new generations of scientists. JILA's success in these endeavors has made it a model for many other joint institutes, including the new Renewable and Sustainable Energy Institute (CU and the National Renewable Energy Laboratory), the Braunschweig International Graduate School of Metrology [PTB (Germany's national metrology laboratory) and the Technische Universität Braunscheig], and the Joint Quantum Institute in Maryland (the University of Maryland and NIST).

Both NIST and CU derive many benefits from being a part of JILA. "From NIST's perspective, there are many benefits to this partnership," explained Tom O'Brian, head of NIST's Quantum Physics Division. "One benefit is that JILA has proven itself to be a unique training ground for scientists wanting careers in precision measurement at NIST in both Boulder and Gaithersburg. The institute provides a steady stream of scientists with a unique perspective on precision measurements who often take scientific and managerial leadership positions at NIST. NIST Physics Laboratory Director Katharine Gebbie is an excellent example of this process. Another is Gretchen Campbell, who was a postdoc at JILA with Jun Ye, before becoming the first woman Fellow at the Joint Quantum Institute."

Former JILA Chair Andrew Hamilton, whose term ended December 31, 2010, is equally enthusiastic about the benefits to CU. "JILA is a great deal for us," he said, adding that "NIST consistently provides a substantial fraction of the external funding for JILA. Plus, NIST's JILA Fellows teach at CU for free and fully participate in training graduate students and postdocs. It's simply wonderful for the university to have JILA located on its main campus."

Hamilton touted JILA's management style of shared governance, or oligarchy, that was created by its founders in 1962. "All major issues are decided by votes of the Fellows," he explained. "The position of JILA Chair rotates every two years to ensure that no one person gains excessive influence over the administration of JILA and that decision making remains broadly shared."

Traditionally, NIST and CU Fellows alternate holding the position of Chair. The Fellows also attempt to regularly mix up the scientific disciplines represented by the JILA Chair. The regular cycling of leadership empowers individuals to put their own vision into play in the governance of the institute — but always with an eye to the advice and consent of their peers. Hamilton noted that JILA's shared-governance model is very different from the management styles at NIST or in the CU departments.

The JILA Chair works closely with NIST's Quantum Physics Division chief, who is typically chosen from the ranks of the NIST Fellows. The division chief is responsible for seeing that NIST Fellows conform to specific demands of being part of a national laboratory and insulating them from other issues where possible, freeing them to focus on research. For instance, NIST Fellows must comply with government regulations requiring preapprovals of scientific communications. However, since JILA is located on the CU campus, the institute is free from the many security restrictions of the NIST Boulder site just a mile away. "Part of my job is to be both a liaison and a buffer with NIST," explained O'Brian.

O'Brian serves on JILA's Executive Committee with the JILA Chair, and four other Fellows who are selected by the Chair when he takes office. In 2010, these Fellows included Chair-elect Eric Cornell, John Bohn, Margaret Murnane, and Robert Parson. The Executive Committee handles many day-to-day administrative decisions such as proposal approvals, appointment extensions, and the hiring of new research associates. The Executive Committee also includes two nonvoting members: Julia Bachinski, the NIST Executive Officer and Beth Kroger, the JILA Chief of Operations.

Bachinski is responsible for NIST finances and supervises the NIST staff. Kroger manages the finances of the CU Fellows and the CU staff. Bachinski and Kroger work closely together and share a wicked sense of humor and a fondness for chocolate. Kroger, who joined JILA in 2009, is already a big fan of JILA's self government. "I meet with the Chair weekly and talk to Julie (Bachinski) and others to see whether we can just go ahead with a new idea or whether we need to run it by the Fellows," Kroger said. "At the end of the day, the Fellows run the place."

Hamilton agreed. "The Fellows do make all the significant decisions," he said. "Even though I was the Chair, my discretion to do something extended only so far as the Fellows trusted me. I served at their mercy. If they're on your side, it's great because there are some big cannons out there.

"Another nice aspect to this system is that it's hard to screw up too badly."

JILA's 2010 Leadership Team (l–r): Andrew Hamilton, Julia Bachinski, Beth Kroger, and Tom O'Brian Credit: Brad Baxley, JILA

Teamwork at the Frontiers of Physics

Carl Lineberger, Eric Cornell, and Deborah Jin have jointly run JILA's Physics Frontier Center since 2006. Theorist Chris Greene (not shown) recently joined the leadership team. **Credit**: Brad Baxley, JILA

Two tough hombres and a straight-shooting física have been co-leading JILA's Physics Frontier Center (PFC) since 2006. Eric "the Enforcer" Cornell is the frontier center's director and principal investigator (PI). Co-PI Carl Lineberger serves as political commissar and quintessential reader of the Washington, D.C., tea leaves. Co-PI Deborah Jin is the center's ace wordsmith and expert presenter to the outside world. JILA scientists fondly refer to the team as the "junta."

The junta recently invited a new Co-PI, Chris Greene, to join the management team for the frontier center. Greene is the first theorist to co-direct the frontier center (or one of its predecessor group grants) since Jinx Cooper rode off into retirement. Together, the four physicists are orchestrating a comprehensive proposal (due in January 2011) to the National Science Foundation (NSF) for a 5-year, ~$20 million grant (starting in 2011) to support cutting-edge research at JILA.

"The proposal is a real challenge," Cornell says. "We're talking and arguing with 17 other JILA physicists who are helping us write it. This proposal is tricky because we can't just rest on our laurels: We have to come up with ways to work together on research that is bold and innovative.

"Right now, we're looking for ways to emphasize the amazing technical capabilities at JILA and how they can help us explore the frontiers of atomic, molecular, and quantum physics as well as precision measurement."

David Hummer (l) and Carl Lineberger (r) celebrate the 1972 NSF award of JILA's first group grant in experimental atomic, molecular, and optical physics.

Credit: Carl Lineberger

"Our job as the PIs is to figure out what NSF really wants and how best to navigate the proposal process," Jin adds. "But it's worth it. A large grant like the PFC gives our scientists a lot of flexibility."

"A PFC grant gives us control of a larger set of resources than any one individual has," Lineberger explains. "That means we can influence JILA to support the greater good of all the PFC investigators. It helps us keep our world-class institute running smoothly."

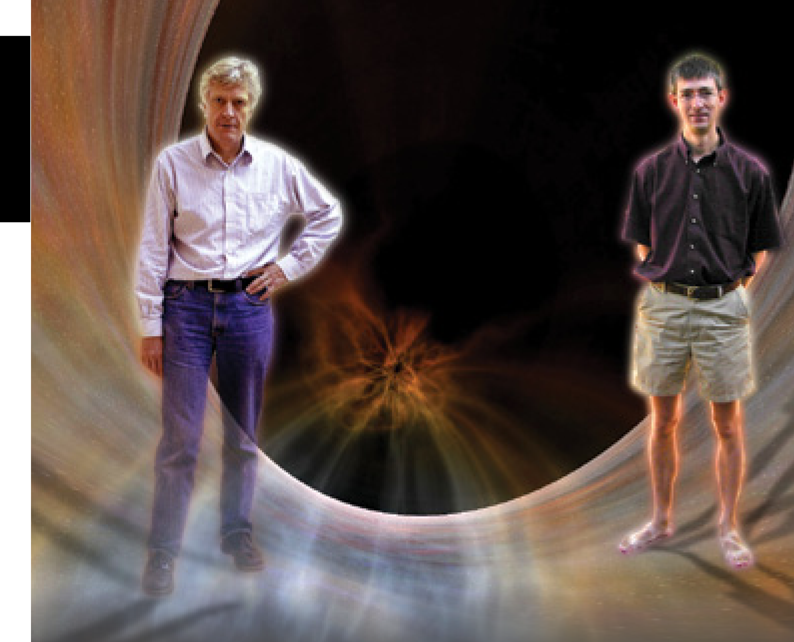
Linberger should know. After JILA lost a large Department of Defense grant in the early 1970s, he became a key player in finding new funding — a role he is still playing 38 years later. In 1972, David Hummer, Steve Smith, and Lineberger secured JILA's first group grant from NSF in experimental atomic, molecular, and optical (AMO) physics for $350,000. This grant quickly grew to half a million dollars. It and subsequent group grants have supported much of JILA's experimental research for 30 years.

In 2003, in the middle of one group grant cycle, NSF administratively converted JILA to a PFC. The new frontier center's funding (then at more than $3 million) didn't change, but the requirements for the grant renewal were transformed. In 2006, JILA found itself competing with other frontier centers for funding as it worked to articulate how JILA's natural propensity for teamwork would translate into five years of collaborative, ground-breaking research at the frontiers of physics. In winning its second PFC grant, JILA's culture of collaborative goal setting and working together on tough research problems became encoded in the requirements for NSF grant funding.

The current proposal-writing effort is part of the most recent competition to become a frontier center. If the January proposal makes it to the final selection stage, Cornell, Lineberger, Jin, and Greene will go to Washington, D. C. to make an oral presentation of the work JILA physicists propose to accomplish during the next five years. Needless to say, everyone at JILA wishes PFC Director Cornell and his team the best in their current endeavors.

"I really enjoy helping JILA in this way," Cornell says. "Being at JILA was a huge component in the success I've had in my career. Now, retroactively, I can pay back some of that by doing things in the background that others once did to support me."

Saving the Second Law and More



Andrew Hamilton and Gavin Polhemus explore a black hole event horizon.
Credit: Andrew Hamilton and Brad Baxley

In November of 2007, Fellow Andrew Hamilton entered into an unusual partnership with Gavin Polhemus, a physics teacher at Poudre High School in Fort Collins. Polhemus had worked with Leonard Susskind at Stanford as an undergraduate and had earned a Ph. D. in physics from the University of Chicago for research on black-hole entropy and matrix theory. Since then, however, he has been raising his son and teaching high school. He was just beginning to think about getting back into doing some research.

At the time, Hamilton and graduate student Colin Wallace had just completed some calculations (based on Einstein's laws of general relativity) on the amount of entropy[1] that might be created inside a black hole as it accreted additional mass. Astonishingly, they found about ten orders of magnitude more entropy being created than Stephen Hawking, the Second Law of Thermodynamics, and the laws of physics would allow.

So, Hamilton and Wallace did what anyone would do with results like these: First, they double checked their calculations to be sure they were on solid mathematical ground. Second, they settled on three possible explanations for their results: (1) black holes violate the Second Law of Thermodynamics, (2) Stephen Hawking made a mistake, or (3) they had blown it big time. In desperation, they scheduled a "below-the-radar" seminar on their findings for CU's high-energy theory group. "It was more like a plea for help," Hamilton remembers. "Colin and I needed some fresh ideas to explain the results we were getting."

Up in Fort Collins, Polhemus heard about the seminar and contacted Hamilton about getting a copy of his paper only to learn that it hadn't been posted yet. Hamilton wanted feedback from the seminar first. "I want to be roasted locally and politely before we put this out before the public," Polhemus recalls Hamilton explaining. Intrigued, Polhemus made the fateful decision to attend the seminar.

After the talk, Polhemus suggested a fourth explanation rooted in string theory and quantum gravity for Hamilton's unexpected results: complementarity. Complementarity accounts for the fact that different observers can experience different quantum realities even though they are, in fact, part of the same event. For instance, a person falling into a black hole and someone else observing the catastrophic tumble from outside the black hole would see very different things. The in-falling person would pass through an event horizon, then take a wild ride through unimaginably extreme conditions before meeting her doom. In contrast, the observer would see her fall into the black hole, get cooked, and later be emitted as Hawking radiation. But, even with such different descriptions, both people would be describing the same event. Nevertheless, they would still be experiencing alternate quantum realities.

This seemingly off-the-wall idea is entirely consistent with one of the central paradigms of string theory, according to Hamilton. Furthermore, string theory and the laws of quantum mechanics both imply that complementarity could extend to all observers inside a black hole once they aren't able to communicate with one another in time. In fact, every minute or so different observers could fall into a black hole and experience a different version of the same reality not only inside the black hole, but also within the event horizon. Over the black hole's lifetime of billions of years, various eyewitnesses could experience as many as 10 quadrillion alternate quantum realities.

Polhemus deduced that Wallace's calculations had summed the entropy in 10 billion possible quantum realities. While this method might work on Earth, it doesn't inside a black hole. A black hole's alternate realities are actually the same experience. This analysis explained the mysterious results, allowed Hawking's predictions to remain intact, and saved the Second Law (which is always a good thing to do in physics).

At Hamilton's invitation, Polhemus signed on to co-author a paper with Wallace and him, and that's when the real trouble started. It turned out to be incredibly challenging to mesh insights about black holes from the perspective of astrophysics and cosmology with string theory and quantum gravity. These disciplines have very different starting points, they use different tools, and their insights are difficult to communicate because of the lack of a common language.

Even though Polhemus and Hamilton managed to bridge these barriers with each other, they discovered that it was going to be quite difficult to publish their new hybrid ideas about the interior states of black holes. No matter whether they submitted to a string theory journal or an astrophysical journal, the referees were uncomfortable with the ideas drawn from an entirely separate discipline that seemed like Greek to them.

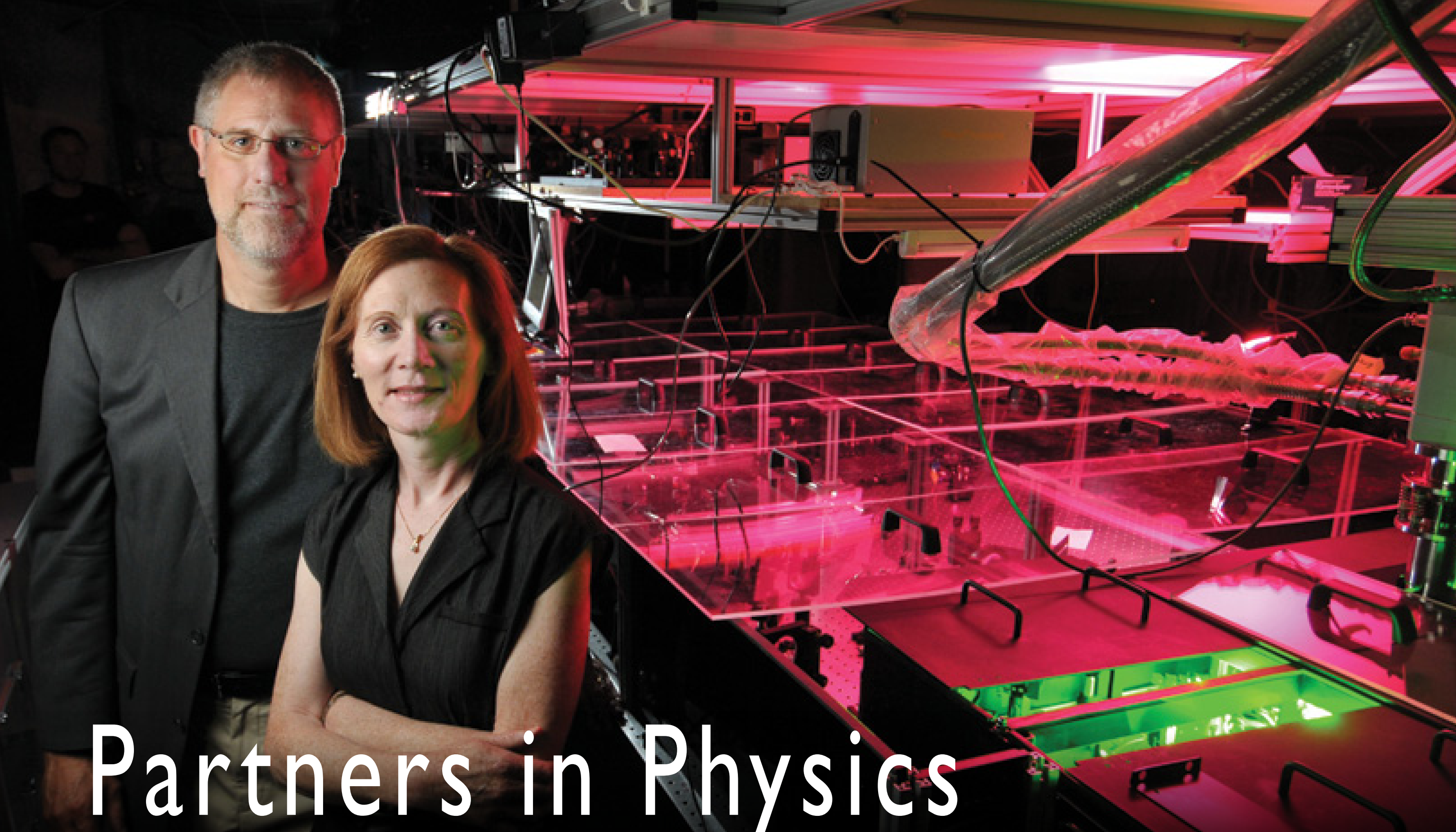
Recognizing this problem, Hamilton and Polhemus decided to prepare parallel papers that were tightly connected, but separated enough to address the particular research communities they were hoping to reach. The first step was to submit two papers to the string theory community — which has accepted both. Next, they plan to submit a paper to the general relativity community, which is known to be skeptical about connections to string theory. Nevertheless, the improbable teammates aren't about to give up.

"Our priority is to understand the interior structure of rotating black holes," Hamilton says, "And string theory has important ideas to offer about the high-energy processes occurring there."

It's obvious that Hamilton and Polhemus like working together. "We continue to educate each other in our own fields," Polhemus says. "I really enjoy coming down here to work with Andrew." Hamilton clearly values the collaboration as well.

During the past two years, Polhemus' research at JILA has been supported by an NSF grant, and he is now a member of JILA. However, Polhemus also plans to continue teaching one or two classes at Poudre High School while he continues his research here. "My research is better when I teach," he says. "When you only work on a research problem for months at a time, it's easy to get distracted and lose your problem-solving skills. Teaching forces you to take any question and solve it right then and there in front of the students. That's what keeps me sharp." And, when you're a key member of an innovative research team, sharp is good.

[1] Entropy is a measure of the microscopic disorder in a system. It may be considered as a measure of the amount of energy that does no work during conversions of energy from one form to another.



Partners in Physics

Henry Kapteyn and Margaret Murnane co-lead a large experimental research group at JILA. They are also husband and wife.

Credit: Glenn Asakawa, University of Colorado

When Henry Kapteyn and Margaret Murnane arrived at JILA in the summer of 1999, they came with a novel solution for the problem of having two highly qualified academic physicists in the family. Although both had secured separate academic appointments, they planned to jointly run a large experimental research group at JILA. With nine years experience with similar arrangements (at Washington State University and the University of Michigan), Kapteyn and Murnane knew that two heads were more than twice as productive as one — for obtaining grants, being able to manage multiple projects in a very large research group, writing journal articles, and educating students on the benefits of teamwork.

"Working with us gives students a great opportunity to learn teamwork," explains Murnane. "People who can work together do better in their careers. In our group, students get a chance to see us disagree — and keep talking — until the answer emerges from a lively discussion. It's easy to listen to each other because we both care about the long-term interests of the group."

"They don't see one person with all the answers," Kapteyn adds. "We both throw ideas on the table, then work together to figure out how to make the best experiment. Our discussions teach our students not to be passive."

The two researchers agree that working in their group often pushes their students outside of their comfort zone. "We encourage them to be passionate about their work and contradict us because they see us doing that with each other every day," Kapteyn says. "They learn not to be afraid to put out their own ideas and discuss them without getting defensive."

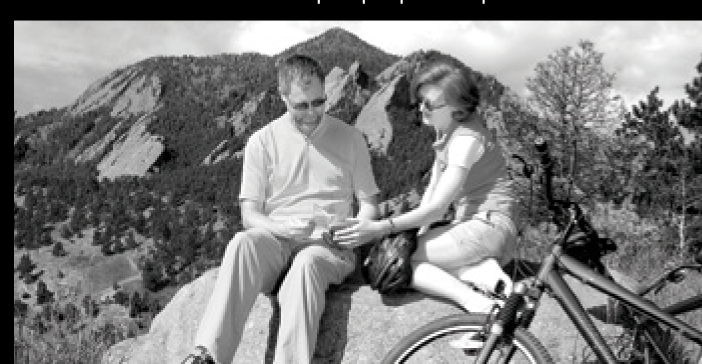
Murnane and Kapteyn agree that their jointly run group is a lot like a small family business where spouses and other relatives spend lots of time working together. Because they spend so much time together at work and at home, the two researchers make a conscious effort to watch out for too much duplication of effort. For instance, they don't go to conferences together. However, they do work hard to get more than twice as many grants as the average group leader in an effort to dispel concerns that two people working together might be less productive than two people working separately.

Their productivity is a matter of record. The K/M group currently has 10 separate research projects underway at JILA. Its laboratories bustle with the commotion of four research associates, 14 graduate students, and one undergraduate student working on such diverse projects as capturing the motion of electrons in molecules, at surfaces and in materials; understanding the limiting speed in magnetic processes; generating laserlike beams of ultrafast x-rays; and manipulating quantum systems with light.

Murnane and Kapteyn are also founding members of the NSF Engineering Research Center for Extreme Ultraviolet Science and Technology, a joint effort of the University of Colorado at Boulder and Colorado State University in Fort Collins, where the center is located. Murnane is the center's deputy director and works closely with another professional couple at Colorado State University, Jorge Rocca and Carmen Menoni. Murnane and Kapteyn are also Chairman of the Board and Senior Vice President, respectively, of KMLabs, a laser optics company they co-founded in 1994.

Remarkably, the couple is able to leave all this behind when they go home. "We've learned to help each other accomplish our individual goals — so there never is any long term disagreement," Murnane says. "We try to help each other relax and stay fit and laugh. We go to cafes, and we cycle a lot."

Even though they make their partnership work at home and in the lab, Murnane and Kapteyn recognize that their level of collaboration is still not the norm for married couples in physics. "It's becoming more common," Kapteyn reflects, "We were among the first truly joint couples, and we proved it can work." As a result, he and Murnane would like to see more universities open up to partnerships like theirs.



Henry Kapteyn and Margaret Murnane mountain biking in the foothills near Boulder, Colorado.
Credit: Casey Cass, University of Colorado

Credit: Brad Baxley, JILA

Partners in Physics: Theory Team

Theoreticians Agnieszka Jaroń-Becker and Andreas Becker found themselves faced with a peculiar conundrum that can arise when a married couple works together in the same field: finding employment near to one another. However, they recently worked out a solution that translates well into both home and work life.

The solution was moving to the United States from Europe, where long-distance commutes were making time with a family difficult. "Universities in the U.S. make it easier for a couple to have more than one career," Becker said. "Bigger universities have more opportunities and can therefore attract better employees."

In essence, JILA offered better professional opportunities for both theorists than were available in Germany. By coming to Boulder, they hoped to work together and establish their careers for the long term. Their common goals were particularly important since they also have a daughter, four-year-old Anna Sophie.

Anna Sophie is enrolled in day care, which "she absolutely loves," according to Jaroń-Becker. Day care allows both parents to work full time. However, since Jaroń-Becker's schedule is more flexible, she is usually the one to take time off when Anna Sophie is sick.

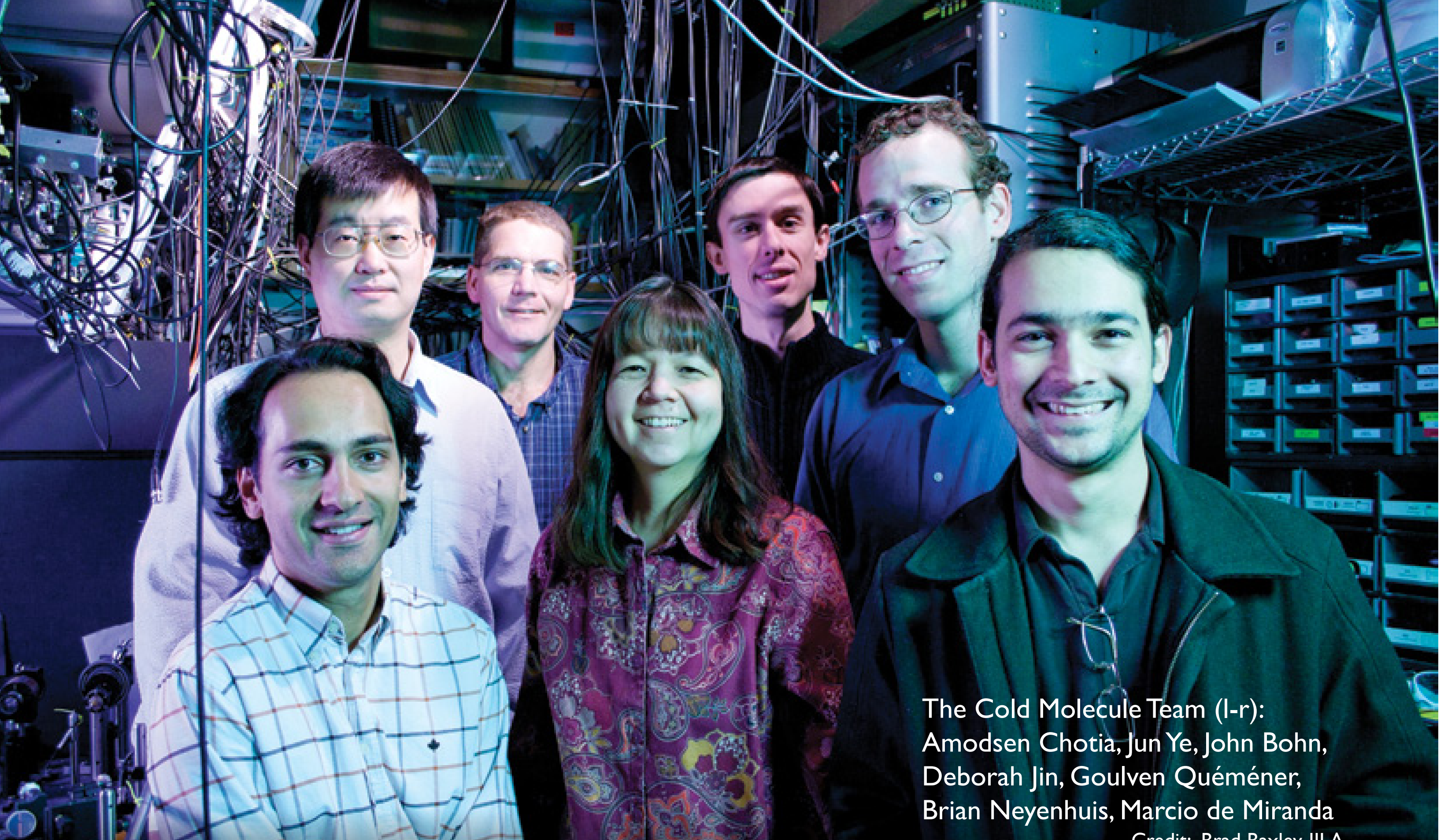
The logistics of conferences can be even trickier than day care. If both Beckers want to attend the same conference, they must take Anna Sophie with them. Unfortunately, conferences often do not provide childcare, forcing parents to hunt for suitable childcare far from home. "This is especially difficult with long-term conferences," says Jaroń-Becker, "since they do not usually provide family housing for attendees."

In contrast to conferences, the Beckers' professional life at JILA is relatively sane. They often collaborate with colleagues Henry Kapteyn and Margaret Murnane, who are no strangers to being a married couple who work together. The Beckers say that Murnane and Kapteyn are understanding and easy to communicate with. Also, since Murnane grew up in Ireland, she has been especially supportive regarding the differences in culture between the United States and Europe.

After two years at JILA, Jaroń-Becker says "any disadvantages are outweighed by the benefits of working as partners both in a career and marriage." Their collaboration results in an "easier, more egalitarian partnership," explains Becker, noting that they understand one another unusually well as a result of working in the same field. And, while issues from work may find their way home, they both benefit from a mutual understanding of the nuances of their careers.

In fact, the Beckers insist that their marriage and career "really are just like any other relationship." Problems and solutions depend on the individuals involved and the relationship's particular dynamics. "Scientific careers are not all that straightforward," says Becker, "and you have to take opportunities as they arise." The opportunity to work together led them to JILA. – Samantha Evans

Agnieszka Jaroń-Becker, Andreas Becker, and Anna Sophie Becker
Credit: Samantha Evans



The Cold Molecule Team (l-r): Amodsen Chotia, Jun Ye, John Bohn, Deborah Jin, Goulven Quéméner, Brian Neyenhuis, Marcio de Miranda
Credit: Brad Baxley, JILA

First Contact

Long ago (by research standards), the W. M. Keck Foundation donated \$1.5 M for JILA research on ultracold molecules. These curious entities did not exist anywhere in the Universe in March of 2003 when the grant was awarded. However, Fellow Carl Wieman had a vision not only of investigating molecules made from ultracold atoms of potassium (K) and rubidium (Rb), but also of enticing Fellows Deborah Jin and Jun Ye into collaborating and eventually taking charge of the endeavor. Seven years later, he has succeeded on all counts.

Carl Wieman
Credit: Joel Frahm

"From the early results we had from my lab and then Debbie's lab as well as the interest and activity of Murray (Holland) and Chris (Greene), this ultracold molecule stuff seemed like it had a lot of potential for leading to exciting new things," Wieman said.

"I also had the ulterior motive that it was a good opportunity to bring together the different, but exceptional, talents and technologies that Debbie and Jun embodied," he added. "Watching their careers, I had been thinking for a while that if there were the right project to do this, it would lead to something spectacular.

"With the Keck money, all the pieces fell into place. I am very happy to see how right I was in my expectations of how successful a Debbie-Jun collaboration would be, particularly one that tied in with the superb JILA theoretical expertise."

Wieman makes the creation and characterization of ultracold KRb molecules sound routine. However, the scientists who worked for seven years to make it happen tell a different story. In the beginning, for example, theorist John Bohn teamed up with Fellows Jun Ye and Heather Lewandowski to work on a set of experiments with cold OH molecules that explored different aspects of dipolar collisions and chemical reactions.

Wieman started off in a different direction, convincing graduate student Josh Zirbel to change his thesis project and work on making ultracold KRb molecules. Zirbel moved into empty lab space in the JILA basement that had originally been part of the library with a spiral staircase to the 1st floor. The space was small, warm, empty, windowless, and sported a drain pipe-sized trench through the middle of the floor. However, it had the big advantage of being right next to the Ye labs. Zirbel recalls Wieman wrapping up his first tour of the new space with, "Okay, this is where you're going to do the cold molecule experiments."

Zirbel remembers thinking, "there's no way we can put all the stuff we need in here." He spent some time trying to get his arms around building a really complicated experiment in the tiny new space. He ordered desks and equipment. In May, an empty table was donated to the cause, and Hans Green installed an overhead rack. As the new lab began to take shape, Wieman was busy successfully convincing Kang-Kuen Ni to come to JILA to do her graduate work under him on the cold-molecule project.

"I wasn't taking JILA too seriously until Carl Wieman sent me two emails," Ni recalls. "In them, he laid out a plan for a very comprehensive education in research, and suddenly there was no way to say no. I liked the idea of getting experience building brand new apparatus."

When Ni arrived in the Fall of 2003, the donated table was still pretty bare, and she got her wish. What she didn't anticipate was how long it would take to bring the dream of making ultracold ground-state KRb molecules into reality: There were lasers to make, characterize, and tune to specific atomic transitions for laser cooling and trapping of atoms. One laser would be dedicated to laser cooling. In addition, the experiments required electronics, vacuum systems, amplifiers, and mechanical mounts. One part that was supposed to be a novel magnetic trap for making a Bose-Einstein condensate turned out to be unstable. It had to be taken apart and reassembled using a more standard design.

Early in 2004, Ye's graduate student Lisheng Chen began working with Zirbel to explore photoassociation of K and Rb atoms into Feshbach molecules. These explorations didn't end up panning out, but in the process Chen built a new Ti:Sapphire laser that would play a role in successful experiments later on down the road.

In the spring of 2006, Ni went to a cold molecule conference. "When I came back Debbie was in the lab," she says. "Then Carl came in to tell me he was leaving to found a physics education research group at the University of British Columbia (UBC)." Wieman's main focus was no longer going to be AMO physics. Ni and Zirbel would soon have a new thesis advisor: Debbie Jin!

"Debbie stepped in when it was clear Carl was leaving," Zirbel recalls. "Debbie would come by the lab and poke around the experiment. She worked with us to get the Feshbach molecules to work." By the end of the year, the group had the first firm evidence of molecule formation, but they were exhibiting a much shorter lifetime than they should have been.

"This was a very discouraging time," Ni recalls. "I was in my fourth year and Josh was in his sixth year, and we still had no papers to show for all our efforts. It's really hard to do something no one has ever done before. There were so many times when we just wanted to quit."

Fortunately, however, things were about to change. Avi Pe'er joined the group in 2006 and immediately began brainstorming ways to transfer Feshbach molecules of KRb into their ground state. He revived a widely tunable laser Lisheng Chen had built for the project early on and began thinking about combining a frequency comb with ultracold gas experiments.

The complexity of trying to get the cold Feshbach molecules into their ground state prompted Pe'er to start working with theorists Paul Julienne of NIST and Svetlana Kotochigova of Temple University. They spent hours conversing via Skype about this complicated problem. Within a few months, they published a joint theory paper outlining what would turn out to be a good road map for making ground-state KRb molecules.

Later in 2006, Ye and Bohn talked with Silke Ospelkaus in Germany about the possibility of her doing a postdoc at JILA. Ospelkaus had read the theory paper by Pe'er and his colleagues and was anxious to try and make their proposed method work in the lab. In 2007, Ye and Jin jointly hired Ospelkaus, who, up until that time, had been one of the group's major competitors in quantum gas research.

Ospelkaus was the catalyst that gelled the collaboration between Jin and Ye. And, things changed quickly after she arrived at JILA. "Silke really helped us out," Ni says. "She was determined and efficient. Plus she had already succeeded in making Feshbach molecules during her graduate research." With Silke's help, the group finally perfected the apparatus for making ultracold KRb molecules.

"OK, one minute we had a signal, then we didn't," Ospelkaus recalls. "We had to work hard to get the Feshbach molecule signal,

continued on page 10

Josh Zirbel and Kang-Kuen Ni in the new cold-molecule lab.
Credit: Kang-Kuen Ni

Silke Ospelkaus
Credit: Greg Kuebler

but as soon as we did, we had to figure out why their lifetime was so short." The researchers soon figured out that the trap laser was responsible for destroying the molecules, and a new trap was built. "From then on, we were studying the collective properties of Feshbach molecules and the individual atoms," Zirbel says.

Around this time, Brian Neyenhuis and Marcio de Miranda from the Ye group joined the project. Miranda provided a multipurpose frequency comb. This laser, together with Chen's Ti:Sapphire laser, would prove critical in making the transition from Feshbach molecules through an intermediate state into the ground state.

"We were doing the experiment in two different rooms," Ospelkaus explains. "One lab had the frequency comb, and the Keck lab (the original small, windowless converted library space) had the main apparatus. We were Skyping each other over the Internet to be sure everything was working."

"We were scanning lasers for hundreds of gigahertz, and we had to turn the knobs by hand," she remembers, noting that the input from Julienne and Kotochigova on where to look for the signals was absolutely essential.

"I remember the day during the summer of 2008 when we got the signal from the ground-state molecules," Ospelkaus says. "We knew generally where to look for it, but it was still like searching for a needle in a haystack. But, we found it the second day! That was really a nice moment." Predictions made by Julienne and Kotochigova had proved invaluable in quickly zeroing in on the signal.

"We were all working together during the summer of 2008," Zirbel remembers. "The collaboration did amazing things while I was also writing my thesis." A *Science* paper authored by Ni, Ospelkaus, Miranda, Pe'er, Neyenhuis, Zirbel, Kotochigova, Julienne, Jin and Ye on this work is now considered seminal for the entire field of ultracold molecule research. (See "The Polar Molecule Express" in the Fall 2008 issue of *JILA Light & Matter.*)

The next year also turned out to be challenging. The researchers were dealing with a completely new system, unlike any other in the world. The goal now was to determine the nuclear spin states of the ground-state molecules. Everything was new and had to be figured out. Jin and Ye were now working closely together on the project, and Jin was in the lab nearly every day. In the face of some big setbacks, Ospelkaus continually urged the group to keep moving and not get stuck in a rut.

Once again, the experimentalists turned to their theorist colleagues for assistance. This time, John Bohn and his postdoc Goulven Quéméner offered valuable insight into making KRb molecules in their lowest nuclear spin state. This amazing accomplishment opened the door to explorations of ultracold-molecule chemistry.

During this highly productive period, Dajun Wang joined the group. Bohn and Quéméner worked on developing new theory to describe the effect of electric fields on elastic collisions of ultracold polar molecules. In early 2010, the new chemistry experiments produced a rash of seminal papers, the first in *Physical Review Letters*, the second in *Science*, and the third in *Nature* (see "Redefining Chemistry at JILA" in the Spring 2010 issue of *JILA Light & Matter*). Ospelkaus and Ni, who had worked together as a team for three years, were first and second authors on all three papers.

After seven years of grueling work, Ni and her colleagues had produced a complex apparatus that could produce ground-state KRb molecules almost with the push of a button. With that accomplishment, Ni graduated and began a postdoc at CalTech. The award of the 2010 DAMOP thesis prize not only confirmed her individual achievements as a graduate student, but also the incredibly successful collaboration of many exceptional JILA researchers.

The excitement generated by the recent breakthroughs in ultracold-molecule chemistry cannot be underestimated. "Our group meetings used to happen on Thursday mornings for an hour," Ni says. "These days, they last from 9:00 a.m. to noon. Chris Greene and Ana Maria Rey come now."

Now the heavy lifting for future cold-molecule experiments and theory has passed on to a new generation of young scientists, including postdoc Amodsen Chotia and graduate student Steven Moses. Both will have the benefit of everything Jin, Ye, and their collaborators have learned during the past seven years.

"It's really been fun," Jin says. "Jun and I bring different expertise. We combined our knowledge of precision lasers and ultracold quantum gases. What we've done is more fun than what happens when people just do the same thing every day. We couldn't have done what we did without both of us — even if it did take Carl leaving JILA to make it happen."

Amodsen Chotia, Marcio de Miranda, and Brian Neyenhuis adjust the cold molecule apparatus.

Credit: Brad Baxley, JILA

Brian Lynch & Jeff Sauter

Credit: Brad Baxley, JILA

TWO FOR THE MONEY

Since 2005, Jeff Sauter and Brian Lynch have worked as a team to supervise JILA's supply office staff and students. In theory, Sauter is responsible for orders from NIST while Lynch handles CU orders. In reality, "we all do the same job," says Sauter. "Our system is set up to handle both CU and Federal accounts."

At first glance, this complex blending of two sets of rules and regulations looks complicated. But Sauter and Lynch make their cooperative leadership style look easy. They have daily discussions (replete with banter and good humor) about how things are working. They also put into practice a shared philosophy of giving their customers what they need.

For instance, JILA operates under two different sets of purchasing regulations that differ on how rush orders should be handled. So anytime there's a rush order, Sauter and Lynch work some financial wizardry to make sure JILA scientists get what they need as quickly as possible. The wizards, in this case, also include Julia Bachinski, NIST's Administrative Officer, and Beth Kroger, JILA's Chief of Operations.

But there are differences. Only Sauter and Dave Errickson, JILA's building proctor, can process NIST orders with government credit cards.

Ana Maria Rey
Credit: Brad Baxley, JILA

In Theory, Team Players Win

Theorist Ana Maria Rey works with both experimentalists and theorists to uncover the fundamental principles that govern our world. Although she works closely with Fellows Jun Ye, Dana Anderson, and Murray Holland, her team efforts aren't limited to the halls of JILA. She's also involved in two research projects with the condensed-matter theory group in the University of Colorado's Physics Department, as well as endeavors at Penn State, the Joint Quantum Institute (NIST-Gaithersburg and the University of Maryland), George Mason University, the University of Sheffield, and Harvard University.

Rey does have help from three graduate students (Chester Rubbo, Michael Foss-Feig, and Shuming Li) and three research associates (Javier von Stecher, Kaden Hazzard, and Salvatore Manmana). Each works on a different project (from Rey's total of nine). Even with their assistance, Rey still must spend time visiting her long-distance collaborators, while others come to JILA to see her. All in all, her professional life is very full.

At JILA, Rey is working with the Jun Ye, Murray Holland, and Dana Anderson groups on a variety of interesting projects. For instance, Anderson, Holland, and Rey want to understand how to implement the photorefractive effect, which occurs in some crystals that change their refractive index in response to light. This effect is a key process in holography. The team wants to implement it with cold atoms in an optical lattice. The project started with Anderson's vision of doing quantum signal processing with atoms. A natural candidate for making this idea work is an optical lattice, the physics of which is one of Rey's specialties. This new effort is interrelated with Holland and Anderson's long-standing interest in atomtronics (see *JILA Light & Matter,* Winter 2007).

Rey and Ye's collaborative efforts include (1) understanding the frequency shifts induced by collisions in the strontium (Sr) optical atomic clock, (2) a new design for quantum computers, and (3) quantum simulations in which the researchers use Sr atoms to mimic the physics of strongly correlated condensed-matter systems (i.e., solids and some liquids). In the latter project, Rey and Ye also work with Michael Hermele and Victor Gurarie in the condensed-matter theory group in CU's physics department.

Rey also teams up with Hermele and Gurarie in the development of a theory of quantum magnetism in alkaline earth atoms. Gurarie and Rey, in turn, are collaborating with Leo Radzihovsky to understand the formation of Feshbach molecules in an optical lattice. "My collaboration with researchers in CU's physics department is great," Rey says. "We have a wonderful synergy. They see the problem from the condensed-matter perspective, and I see it from that of atomic physics. This difference in viewpoints allows us to attack the problem in different ways."

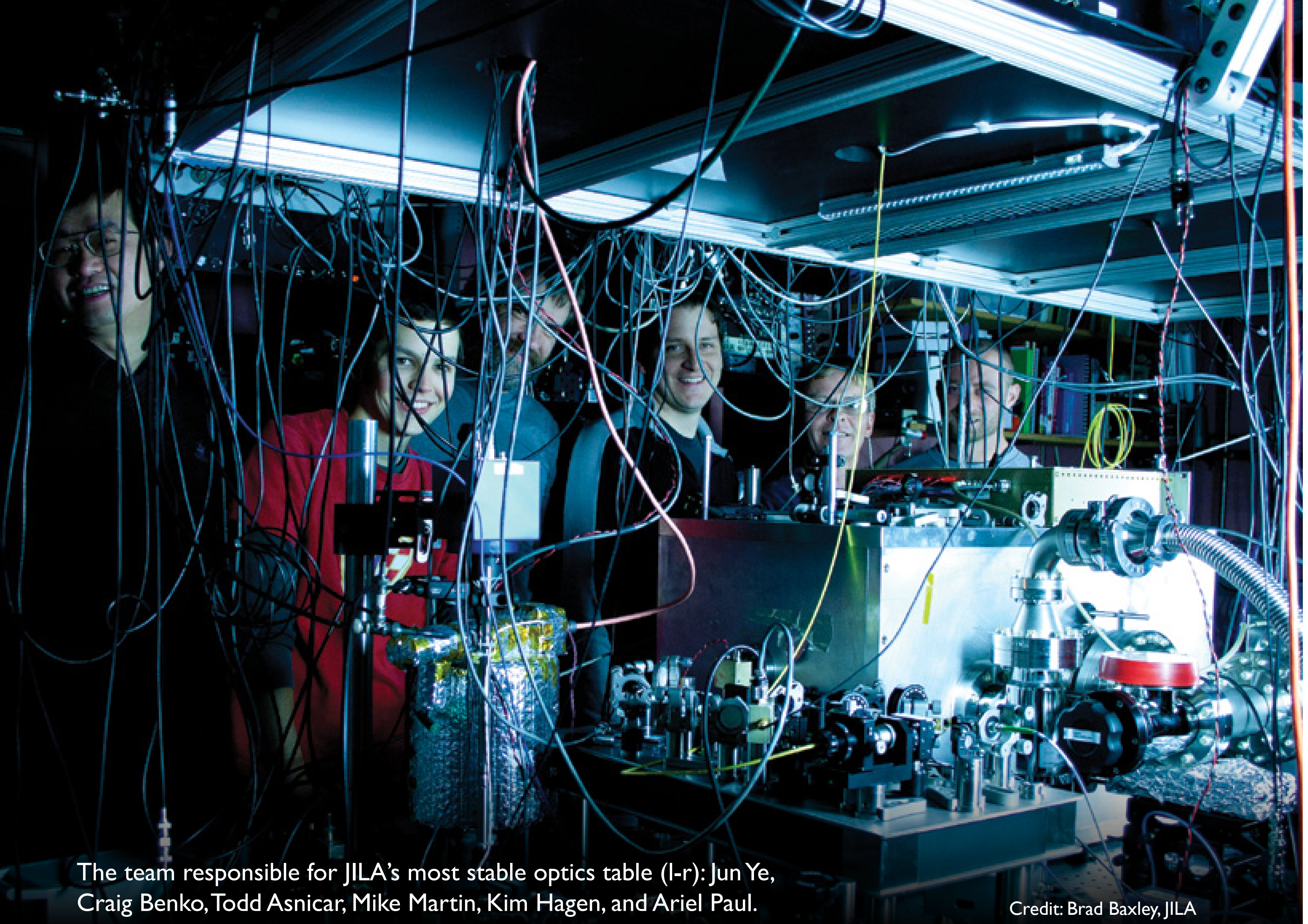
Long-range partnerships with theorists offer some of the same advantages. Rey has been working with former JILAn Keith Burnett (currently at the University of Sheffield) since her graduate student days. They are attempting to understand the creation of macroscopic superposition states in optical lattices. Such an understanding will be useful in the design of optical atomic clocks and precision measurement.

Rey has also continued to work with theorist Eugene Demler at Harvard University, a collaboration that began when she was a postdoc. With the assistance of JILA postdoc Javier von Stecher, they are working on understanding the behavior of electrons in carbon nanotubes.

Rey also enjoys long-range collaborations with experimental physicists. She is currently working with David Weiss at Penn State on trying to understand the dynamics of atoms in two-dimensional optical lattices. She also collaborates with Trey Porto at the Joint Quantum Institute on how to simulate a condensed matter model known as the Kondo lattice model. The simulation uses alkali atoms in two different vibrational states in the lattice. The Kondo lattice model is used to represent the physics of strongly interacting heavy fermion materials. Rey says that in such metallic compounds, electrons are strongly affected by interactions and can acquire a huge effective mass.

And if all this teamwork weren't enough to keep her busy, Rey is also working with Charles Clark of the Joint Quantum Institute and Indu Satija, a guest scientist at NIST and a professor at George Mason University, on a new book for Cambridge University Press. The book, to be titled "Bunching and Anti-Bunching in Ultracold Atoms," focuses on improving the understanding of an interferometry technique known as noise correlations that is based on time-of-flight images. The technique has been demonstrated at JILA by the Debbie Jin group and is widely used by other ultracold-matter researchers.

The Rey Theory Group (l-r): Salvatore Manmana, Shuming Li, Gang Chen, Ana Maria Rey, Kaden Hazzard, Javier von Stecher, Michael Foss-Feig, and Chester Rubbo.
Credit: Brad Baxley, JILA



The team responsible for JILA's most stable optics table (l-r): Jun Ye, Craig Benko, Todd Asnicar, Mike Martin, Kim Hagen, and Ariel Paul. Credit: Brad Baxley, JILA

The Day the Lab Stood Still

How JILA teamwork made it possible to remodel half of Jan Hall's laboratory in an effort to build the world's most stable laser

In 2009, graduate student Mike Martin launched a new project to build the world's most stable laser for the Ye group's strontium-based optical atomic clock. From the get go, Martin knew he'd need some serious help. First his advisor, Fellow Jun Ye, asked his mentor and friend Nobel Laureate Jan Hall for about half the space in his quiet, climate-controlled lab deep inside the Ye labs. Ye also arranged for Lisheng Chen to come to JILA for six months as a visiting scholar. Chen is a specialist in laser stabilization from the Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences. He received his Ph.D. in physics in 2005 from CU (working with Ye). Chen arrived at JILA in February of 2010.

Martin and Chen immediately contacted Todd Asnicar of JILA's instrument shop. The two researchers were going to need an optics table that was more stable than any ever built at JILA. They also needed air filters to purify the air in the lab, a vacuum system to keep the laser cavity at a pressure of 10^{-8} Torr or less, and a mechanism to isolate (and insulate) the laser cavity from the ambient conditions in the room so it could be cooled to about 10 degrees C below room temperature and isolated from lab vibration noise. Perhaps the biggest challenge was that all this equipment had to be installed in Hall's lab without disrupting Hall's research in the other half of the room.

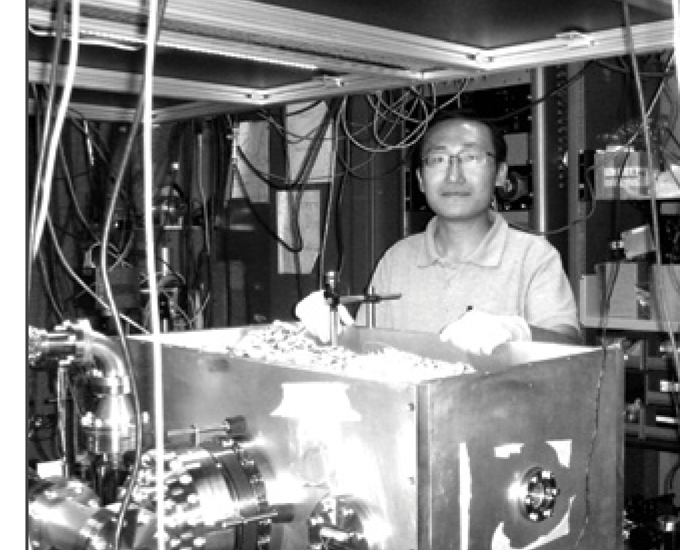
The next two months were a prime example of teamwork. Asnicar recruited Kim Hagen (who soon took over leadership of the project), Ariel Paul, and Hans Green to work on the complex task of remodeling half of Hall's lab to meet Martin and Chen's goals. "The whole project was super professional," said Hagen. "Mike's an easy customer to work with. He came up with an idea, then brought it to us and asked what we thought of it. Then we had lots of debating about how best to accomplish what he wanted."

"We iterated the design," added Paul. "It was a very organic process between us and the scientists."

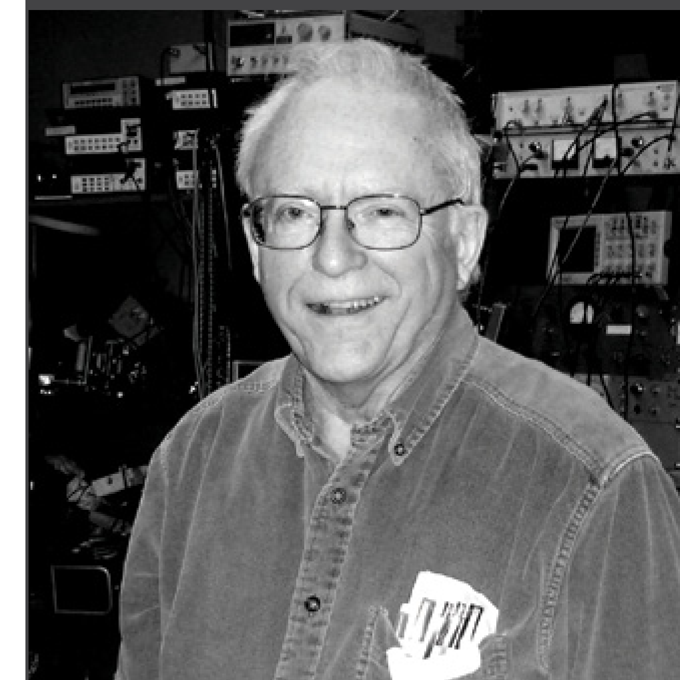
Whatever the magic was that happens between the Instrument Shop staff and JILA researchers, it worked. The new optics table, the cavity box, and upper shelving only begin to tell the story of the creative insights that went into designing all the parts. For instance, second shelf above the table contains a HEPA filter that keeps the air around the optical cavity clean. The new optics table is actually an actively stabilized table on top of a regular optics table. Because it can sense vibrations and use piezo-electric transducers to cancel them out, the top table is completely vibration free. It sits on 4-inch-thick isolation pads, which, in turn, sit on the lower table. This table, which is much lower than a normal optics table sits on four short (8-in) legs, each of which was custom machined from aluminum chunks. The custom legs cancel tilt and height variations in the floor, evening out roughness and absorbing vibrations.

The optics structure consists of an optical cavity inside a copper box, which provides a passive temperature shield. The copper box sits inside a small aluminum vacuum chamber, which, in turn, sits inside a larger aluminum vacuum chamber. The larger vacuum chamber lowers the pressure of the nested boxes to about 10^{-3} Torr. The smaller chamber lowers the pressure to at least 10^{-8} Torr. The apparatus can hold different laser cavities. Two of these were made in the Instrument Shop. Another cavity, made of monocrystalline silicon (Si), was manufactured by the Physikalisch-Technische Bundesanstalt (PTB), Germany's National Metrology Institute. This novel Si cavity is a result of collaboration between the Ye group and PTB. It is transparent to infrared radiation and has been tested against another Si optical cavity at PTB. All of these optical cavities are designed to be supported in a configuration that is minimally sensitive to any residual vibrations that the vacuum chamber might have.

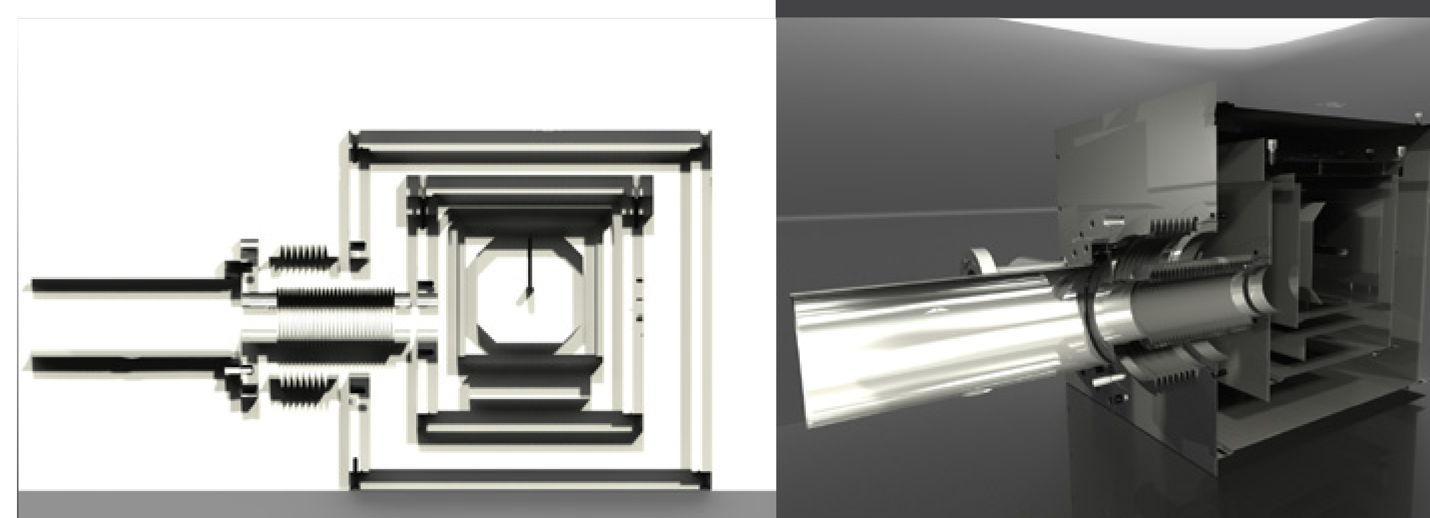
A precision laser exits its thermos-bottlelike optical cavity at exactly 698 nm on a state-of-the-art optics table enclosed by plastic curtains. The stage is now set for improving the performance of the strontium optical atomic clock, which is already one of the most precise atomic clocks in the world. But, just to be sure he's getting the best possible performance from his new clock laser, Martin doesn't take any data until after 10 p.m. at night when everyone else has left for the night. It may have taken an entire JILA team to assemble the new laser cavity and table, but, in the end, testing and refining the new laser is Martin's job.



Lisheng Chen Credit: JILA



Jan Hall Credit: JILA



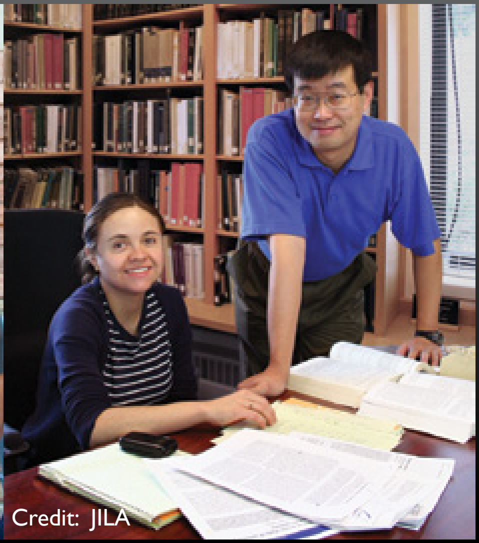
Drawings of the new laser's glass optical cavity nestled inside three boxes: a copper box, a small vacuum chamber, and a larger vacuum chamber. The larger vacuum chamber will have a pressure of ~10^{-3} Torr, and the smaller chamber at least 10^{-8} Torr.

Credit: Brad Baxley, JILA

JILA Scientific Achievment Award

On August 31, 2010, the Ye Group's optical atomic clock team received a JILA Scientific Award for creating a 50-fold improvement in the uncertainty of the atomic collision-induced frequency shift of the neutral strontium (Sr) optical atomic clock. The clock enhancement was suggested by a new theory developed by Fellow Ana Maria Rey. It was successful in preventing collisions between fermionic Sr atoms in slightly different states during the excitation process of the clock transition. Graduate students and research associates on the clock team each received $100 as part of the award. Clock team members are (l to r) Yige Lin (scientific support), Michael Bishof (graduate student), Mike Martin (graduate student), Sebastian Blatt (graduate student), and Matthew Swallows (research associate). Right: Fellows Ana Maria Rey and Jun Ye.

Credit: Brad Baxley, JILA


Credit: JILA

Kudos to...

Mitch Begelman for the publication of the second edition of *Gravity's Fatal Attraction: Black Holes in the Universe*, which was co-authored with Martin Rees.

Jan Hall for winning the Governor's Award for High Impact Research in the fundamentals of laser technology.

Margaret Murnane for being appointed to the President's Committee on the National Medal of Science.

Cindy Regal for receiving the University of Colorado's first-ever Clare Booth Luce Professorship Award. The $645,000 award, which is designed to "encourage women to enter, study, graduate, and teach in science, mathematics, and engineering," will fund Regal's teaching and research for the next five years.

Kaden Hazzard for receiving a prestigious Springer Thesis Award, including a cash prize of 500 Euros. Springer will publish Hazzard's thesis, entitled "Quantum Phase Transitions in Cold Atoms and Low Temperature Solids," as a book, which will be available in March of 2011. The Springer Thesis series is a collection of the very best Ph.D. theses from around the world. Each was selected for scientific excellence and the high impact of its contents to the pertinent field of research.

JILA Light & Matter is published quarterly by the Scientific Reports Office at JILA, a joint institute of the University of Colorado and the National Institute of Standards and Technology.

The editors do their best to track down recently published or upcoming journal articles and great research photos and graphics. If you have an image or a recent paper you'd like to see featured in the newsletter, contact us at sro@jila.colorado.edu.

Please check out this issue of *JILA Light & Matter: Fall 2010* online at http://jila.colorado.edu/research/ where you can find supplemental multimedia that may be associated with the articles.

Managing Editor —
Julie Phillips

Editor —
Lorraine Volsky

Art & Production —
Brad Baxley

JILA, University of Colorado
440 UCB
Boulder, CO 80309-0440

http://jilawww.colorado.edu

(303) 492-7861
sro@jila.colorado.edu