NATIONAL HIGH MAGNETIC FIELD LABORATORY

# REPORTS

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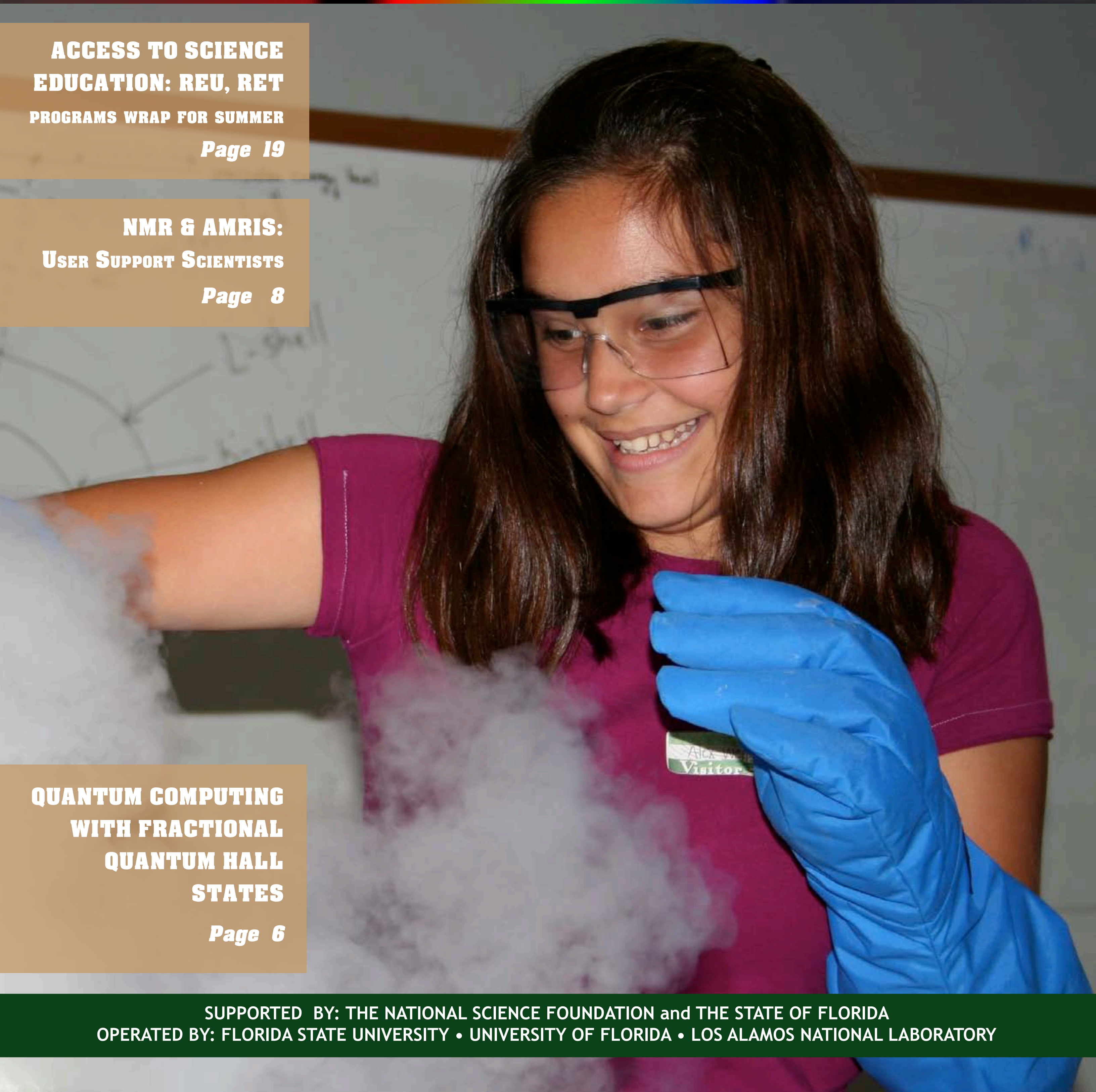

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# NHMFL REPORTS

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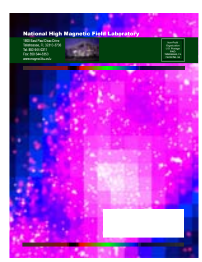
**On front cover:** Summer's SciGirls camp participant Alex Wells cooks up nitrogen ice cream. For more on ScGirls and the lab's education initiatives, see page 19.




**On back cover:** A cell as seen with a traditional wide-field microscope appears in blue. The same cell, as seen using the palm technique, appears in violet. Read more about the technique that enables this breakthrough in cell biology on page 23.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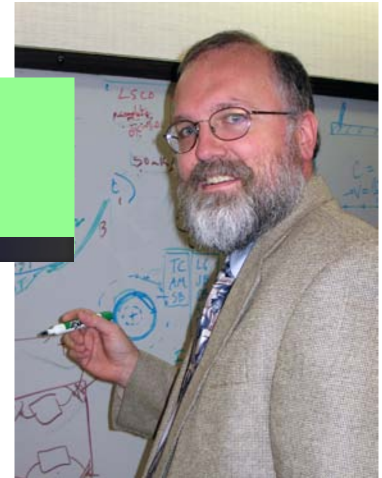
# FROM THE DIRECTOR'S DESK



Greg Boebinger

The "Director's Desk" might be a tad brief this issue, because the director's real desk, and cortex, are crowded with the final versions of our five-year National Science Foundation renewal proposal just prior to clicking the "submit" button to send it off to the NSF. My thanks to all at the MagLab who contributed. In particular, the **Science Council** did a great job pulling together the many scientific opportunities for future high magnetic field research. You can see the (mostly smiling) faces of the Science Council on page 6.

Being a user program first and foremost, I also thank those outside the MagLab's four walls who greatly contributed to our renewal proposal. These include many users and friends of users who helped develop white papers, new initiative requests, and specific suggestions to earlier drafts. A special thank you to the 22 members of our **External Advisory Committee**, who either attended or participated through other communications. The meeting August 8-9 was very helpful to the MagLab in general and to me personally. Three of the 16 EAC members in attendance flew in all the way from Asia the day before…and all contributed to a detailed conversation about the role and vision for the MagLab over the coming decade. They are a great asset for the laboratory and their dedication is much appreciated.

I'd like to draw attention to a few recent moves among MagLab staff members. **John Miller**, our director of the Magnet Science and Technology division, recently decided to return to the mountains of Tennessee, and to join Oak Ridge National Laboratory on the ITER project. **Mark Bird**, longtime leader of the MagLab's world-leading resistive magnet design team, is doing a great job as interim MS&T director during this…ahem…invigorating time. And, finally, as noted later in this issue, **Chuck Swenson**, the head of our pulsed-magnet design team at the NHMFL/FSU, has moved to the mountains of New Mexico to join the staff and other pulsed-magnet engineers at the lab's Pulsed Field Facility.

The laboratory's pulsed-magnet collaboration, which will continue between the LANL and FSU sites, is a great testament to the cross-site collaborations that we enjoy. Another example is the Magnetic Resonance Imaging program, which has its historical roots at the NHMFL/UF and, with the ultra-wide bore of the 900 MHz magnet, is now growing at the FSU site as well. With the present inclination to overwork the expression "Center of Excellence," it is nice to note that excellence at the MagLab is not constrained to being centered at one single site.

*Greg*

Greg Boebinger

## "CO-WIN" lab nearing completion

The lab's diversity initiative will soon celebrate a major milestone when a Quantum Design 16-tesla Physical Property Measurement System (PPMS) is installed in a renovated lab that will be dedicated to researchers and graduate students from historically black colleges and universities.

Named for the lab's College Outreach-Workforce Initiative, the CO-WIN lab is an outgrowth of a $1.5 million grant from the National Nuclear Security Agency to increase the involvement of minority scientists and their students in cutting-edge research. Kevin Storr, a professor at Prairie View A&M and a visiting scientist at the Tallahassee facility, is the principal investigator on the grant, and Stan Tozer, with the lab's Extreme Conditions Group, is a co-PI.

A large portion of the Magnet Lab's share of the grant money went toward purchasing the automated PPMS system. This equipment is important to early-career researchers because it allows them to perform initial measurements that justify experiments in the higher fields. Once installed, researchers and students will perform initial measurements, characterization of materials, and high-pressure experiments. (At press time, the installation was scheduled for mid-September.)

The grant is supporting two graduate and seven undergraduate students at Prairie View A&M two undergraduates and a postdoctoral student at North Carolina A&T, all of whom will be provided travel support to do collaborative research at Magnet Lab facilities in Tallahassee and Los Alamos, N.M. In addition, the grant supported non- U.S. resident students in the lab's Research Experiences for Undergraduates summer program.

A magnet pit is being readied for the CO-WIN lab, an outgrowth of a $1.5 million grant from the National Nuclear Security Agency to increase the involvement of minority scientists and their students in cutting-edge research.

## DC Field Facility upgrades well underway

Resistive Magnet Operations began a two-month shutdown Aug. 14 to install equipment purchased with a $7.5 million appropriation from the Florida legislature. Once completed, the infrastructure improvements are expected to yield longer run times for the magnets at their highest fields, less noise in the scientists' data, and perhaps even measurements not previously possible.

In a perfect illustration of the expression "timing is everything," one of the transformers scheduled for replacement failed just two weeks before the scheduled shutdown. Here's a breakdown of the improvements:

- **The addition of a 3 million gallon chilled water storage tank.** The new tank is 114 feet in diameter and 40 feet tall. Getting the tank ready for storage is a long and arduous process that involves filling the tank with some cleaning and treating agents, followed by draining it, filling and draining again to rinse, and then a final fill. This process is expected to take about a month due to limitations on how much water can be taken from the lab's well each time. (The lab has an existing 1.3 million gallon tank.)

- **The purchase of new transformers, new controls for the power supplies and other electrical equipment, as well as additional plumbing for the cooling system.** During the shutdown, facilities will install the transformers, upgrade the power supplies, and upgrade and add piping, pumps and heat exchangers in the chiller plant.

You can read more about the upgrades in the next issue of *NHMFL Reports*.

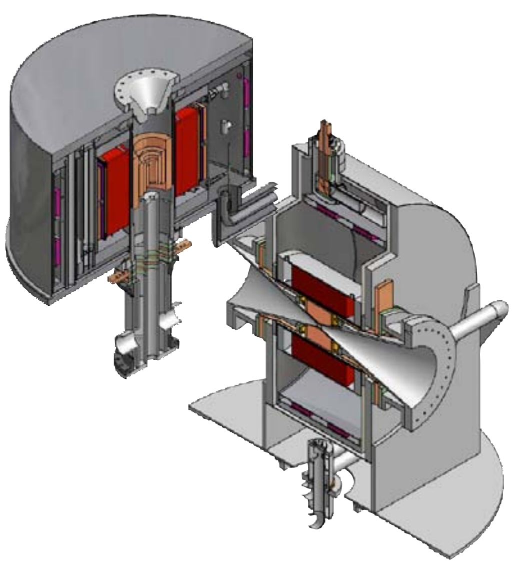
## Technology Demonstration for Series Connected Hybrid completed

A new high-homogeneity resistive magnet has been successfully tested in cell 7 of the DC Field Facility. The new magnet provides 27.6 teslas for extended periods or 29.3 teslas for one hour and includes current-density grading to reduce the z2 term of the field.

NMR maps have been performed. The linewidth is approximately 90 parts-per-million on a 3 millimeter sample and the inhomogeneity on-axis is about 40 ppm over 10 mm. Adjustments will be made in coming months to improve the inhomogeneity and linewidth further. Lab engineers expect to attain inhomogeneity less than 50 ppm over a 10 mm diameter spherical volume. The previous magnet provided about 4 teslas less field and had a broader linewidth.

This magnet employs a different approach to improved homogeneity than that previously employed at the Mag Lab and serves as a demonstration of some aspects of the resistive insert for the Series Connected Hybrid.

Persons interested in using the magnet should contact Bruce Brandt (brandt@fsu.edu) or Merry Ann Johnson (johnson@magnet.fsu.edu). For more details about NMR mapping, contact Arneil Reyes (reyes@magnet.fsu.edu) or Phil Kuhns (kuhns@magnet.fsu.edu).



## Boomerang-shaped liquid crystals focus of new study

A group of researchers from Kent State University's Department of Physics and Liquid Crystal Institute has been awarded a $536,000 grant by the National Science Foundation to study a new class of liquid crystal molecules known for their "boomerang" shape.

As part of the grant, Kent State graduate students will work with the researchers to perform experiments at the Magnet Lab. They'll be searching for new liquid crystalline states of matter, and also focusing on a phenomenon called "flexoelectricity," which is likely to be enhanced by the boomerang shape of the liquid crystals. According to a news release from Kent State, flexoelectricity could potentially be the basis of environmentally friendly micro-power generators.

"Imagine harvesting your legs' energy during walking to charge your cell phone," says team member and associate professor of physics James Gleeson.

With help from a SciGirls camp attendee, Pat Dixon whips up a delicious batch of nitrogen ice cream. This summer's SciGirls camp, which aims to expose girls to interactive science education, was a huge success and resulted in a great deal of interest for vacation camps and summer camps. For more on SciGirls, see page 19.

# *from the* MagnetLab Science Council

Lev Gor'kov

*Science Council chairman*

The paper by Nick Bonesteel presented below briefly describes results of the recent paper[3] by the Bonesteel group at FSU, NHMFL, and S. H. Simon (Bell Labs, Lucent Technologies). It concerns the topological quantum computing (TQC) that is the most fundamental recent concept in the field. Notably, the ideas may find their best realization in the fractional quantum hall effect (FQHE) for two-dimensional electron gas in strong magnetic fields. Among experimentally studied ground states at different filling factors, there exist a few phases found recently where quasiparticle excitations obey the so-called non-Abelian anyon statistics. The latter feature realizes itself due to the two-dimensionality of the problem and is akin to the familiar "knots problem"—one cannot untie a knot on a line that lies on the plane without leaving the plane. Similarly, such topological robustness takes place for the 2D space-time trajectories for fractional quasiparticle excitations. If, for instance, the two world-lines wind around each other ("braid"), such "state" for two excitations is topologically stable. In TQC one identifies "qubits" of information with such "braids" that, thus, are topologically protected. On the other hand, quantum computing is the process of the time evolution of the system in the presence of a weak interaction between excitation. In the *Physical Review Letter*,[3] the authors address the most urgent problem of initiating the process and reading off the results, in other words, the question of quantum gates. The problem translates itself into the operations with many braids, which turns out to be highly non-trivial and cumbersome. Essential progress has been achieved in reducing the problem to a sequence of smaller and easier steps in terms of triplets for the Fibonacci anyons.

## Quantum Computing with Fractional Quantum Hall States

Nicholas Bonesteel, NHMFL

The fractional quantum Hall effect is a remarkable phenomenon. Take a two-dimensional gas of electrons, place it in a strong magnetic field, cool it to ultra low temperatures, and, under appropriate conditions, the electrons condense into a new state of matter. In this new state, current flows without dissipation and the Hall resistance (the ratio of the perpendicular voltage drop to the current) is precisely quantized as a rational fraction of $h/e^2$. More remarkably, when an electron is added to certain of these states, it can break apart, or *"fractionalize,"* into fractionally charged quasiparticle excitations.

Over the past few years an unexpected possible application of this effect has come to light. It has been shown that certain fractionalized quasiparticles can, at least in principle, be used to

SCIENCE COUNCIL

Rafael Brüschweiler | James Brooks | David Larbalestier | Albert Migliori | Carol Nilsson | Glenn Walter build a universal quantum computer![1,2] Recent work by the author, in collaboration with two FSU graduate students, Layla Hormozi and Georgios Zikos, and Steve Simon at Lucent Technologies, has shown precisely how such a quantum computer would operate.[3] To understand our work it is first necessary to review some essential ideas in both quantum computing and fractional quantum Hall physics.

In a quantum computer classical bits are replaced by qubits (short for quantum bits)—two level quantum systems whose Hilbert spaces are spanned by states typically denoted |0> and |1>. Roughly speaking, the power of a quantum computer comes from the fact that for N qubits the dimensionality of the full Hilbert space is $2^N$, which for just a few hundred qubits can be larger than the number of atoms in the universe. Richard Feynman was the first to suggest that it might be possible to exploit this large Hilbert space to perform new kinds of computation, a notion which was dramatically confirmed in 1996 when Peter Shor proved that, using a quantum computer, large integers could be factored into primes in a time which scales only polynomially with the number of digits—an exponential speed up over the best known classical factoring algorithm.

The biggest obstacle to building a quantum computer is the inevitable loss of quantum coherence of the qubits due to their coupling to the environment. Here's where the fractional quantum Hall effect comes to the rescue. Over 15 years ago, Moore and Read[4] showed that, for a particularly exotic form of fractionalization, when a finite number of quasiparticles are present with their positions fixed, there is a degenerate Hilbert space of states whose dimensionality grows exponentially with the number of quasiparticles. Furthermore, these degenerate states are characterized by what are known as "topological" quantum numbers. This means that no local measurement can be used to distinguish them—only global measurements can do this. These states are therefore essentially invisible to the environment and so have a built-in protection against decoherence, making them an ideal place to store qubits.

But do such states, known for technical reasons as non-Abelian states, actually exist? Remarkably, there is reason to think the answer is yes. There is a strong theoretical case that the $\nu = 5/2$ fractional quantum Hall state is precisely the non-Abelian state originally proposed by Moore and Read. More recently, a compelling case has also been made that the $\nu = 12/5$ state (recently detected experimentally at the Gainesville high B/T facility[5]) is also a non-Abelian state, this time one proposed by Read and Rezayi in 1998[6].

And how would one run a program on such a quantum computer? The answer is by dragging quasiparticles around one another in a kind of quantum "shell game." Because they live in a two-dimensional states of matter, when quasiparticles are dragged around one another, their world-lines become "knotted" with each other, forming *braids* in 2+1 dimensional space-time [see Figure 1]. This "braiding" of quasiparticle world-lines is unique to two space dimensions. In 3+1 dimensional space-time, particle world-lines, no matter how convoluted, can always be continuously disentangled from one another.

Associated with each topologically distinct braid there is a unitary transformation that acts on the degenerate Hilbert space. Because this transformation depends only on the *topology* of the braid, it possesses an intrinsic "fault tolerance," a particularly appealing feature of this form of quantum computation. Different non-Abelian states have different rules for determining the unitary operation that corresponds to a given braid. While the rules for the $\nu = 5/2$ state are unfortunately not sufficiently rich for carrying out topological quantum computation, Freedman *et al.*[2] have shown that the braiding properties of the $\nu = 12/5$ state, if it is indeed described by a Read-Rezayi state, *are* sufficiently rich. Their proof, however, did not show how to determine the braiding patterns that would correspond to a given quantum computation.

This is the problem that we addressed in *Ref. 3*. To solve it, it was necessary to explicitly show how various elementary "quantum gates," the quantum analogues of ordinary Boolean logic gates,

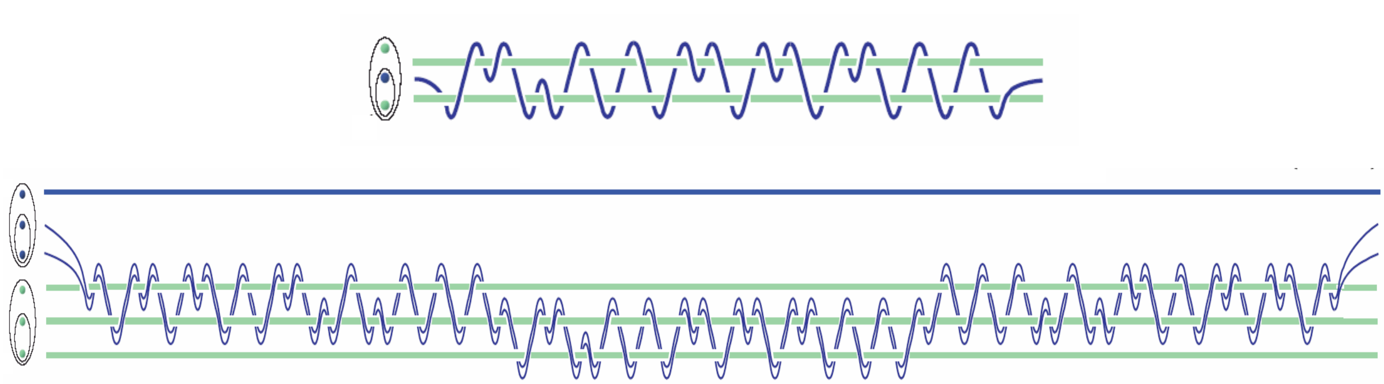


**Figure 1.** Braiding patterns that correspond to a single-qubit operation (top) and a controlled-NOT (CNOT) gate (bottom).[3] Time flows from left to right and qubits are encoded into triplets of quasiparticles. In the single qubit operation (top) the middle quasiparticle of a qubit is woven around the other two quasiparticles of the same qubit. In the CNOT gate (bottom) a pair of particles from one qubit (blue) is woven through the quasiparticles forming the second qubit (green) in such a way that the state of the green qubit is flipped if and only if the blue qubit is in the state |1>. Any quantum algorithm can be decomposed into a series of single qubit operations and CNOT gates, thus the explicit construction of the corresponding braids given here provides a direct proof that universal quantum computation is possible using these quasiparticles.

can be translated into quasiparticle braiding patterns. Our approach to this problem was based on first encoding qubits into the Hilbert space associated with triplets of quasiparticles. The reason for using triplets was that, as shown explicitly,[3] any single-qubit operation can be performed by braiding these three quasiparticles around each other. To carry out arbitrary quantum computations it is also necessary to be able to perform two-qubit entangling gates, for which the standard choice is a controlled-NOT (CNOT) gate, a gate in which the state of one qubit is flipped if and only if the other qubit is in the state |1>. Such a two-qubit gate involves braiding *six* quasiparticles, which is significantly more complicated than braiding three, so much so that any direct brute-force approach to the problem is doomed to fail—there are simply too many ways six strands can become knotted with each other. In *Ref. 3*, we showed that by taking a pair of quasiparticles from one qubit and "weaving" it through the quasiparticles forming the second qubit, it was possible to reduce the problem of finding a two-qubit gate to that of finding a sequence of three stranded braids, turning the problem of constructing a CNOT gate to a series of smaller, tractable problems.

Figure 1 shows a single-qubit braid and a two-qubit braid, both taken from *Ref. 3*. The single-qubit braid corresponds to a particular single qubit rotation (in this case a NOT operation), and the two-qubit braid corresponds to a CNOT gate, constructed using the "divide and conquer" method described above. In the CNOT braid, a pair of quasiparticles from the blue qubit is woven through the quasiparticles of the green qubit in such a way that, if the blue qubit is in the state |0> the green qubit is unaffected, but if the blue qubit is in the state |1> the state of the green qubit is flipped. Since any quantum algorithm can be decomposed into a series of single qubit operations and CNOT gates, our explicit construction of braiding patterns which carry out these gates provides both a direct proof that topological quantum computation is possible for these quasiparticles and a practical recipe for translating any quantum algorithm into a braid.

Needless to say, the technological requirements for physically carrying out these braids will be quite demanding. But, given the inherent advantages of this form of quantum computation—namely the built-in protection against decoherence due to the topological nature of the Hilbert space, and the intrinsic fault tolerance of braiding—it is not out of the question that, in the long run, quantum computers may one day be built out of fractional quantum Hall matter. Even if this does not happen, the realization that the quantum order associated with fractional quantum Hall states can be sufficiently rich to carry out universal quantum computation has provided a surprising link between one of the forefront topics in condensed matter physics and the theory of quantum computation.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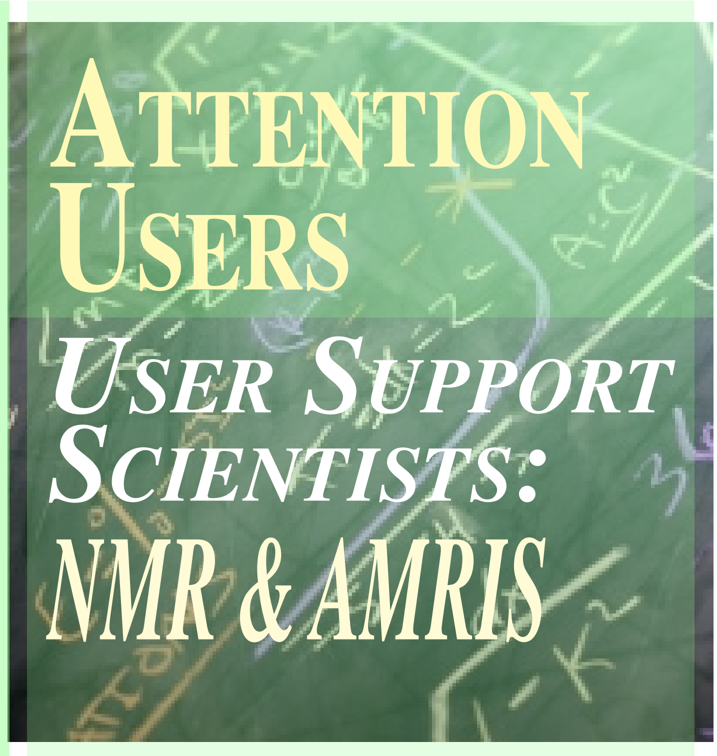
3 Bonesteel, N.E.; Hormozi, L.; Zikos, G. and Simon, S.H., *Phys. Rev. Lett.,* **95**, 140503 (2005).
4 Moore, G. and Read, N., *Nucl. Phys.*, **B360**, 362 (1991).
5 Xia, J.S., *et al.*, *Phys. Rev. Lett.*, **93**, 176809 (2004).
6 Read, N. and Rezayi, E., *Phys. Rev. B*, **59**, 8084 (1999).


## NMR Facility in Tallahassee

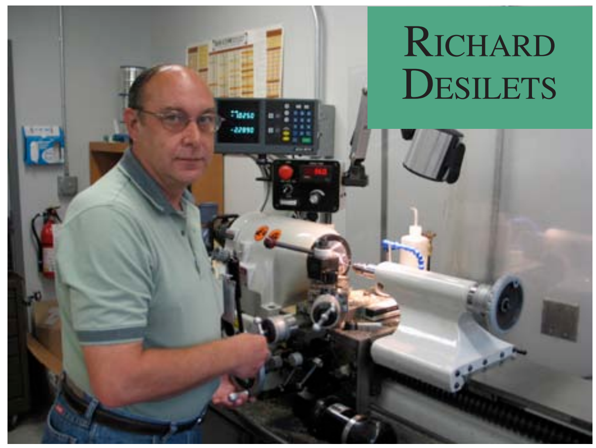
Without skilled scientists, engineers, and technicians we would not be able to open the doors to the Nuclear Magnetic Resonance Spectroscopy and Imaging Program. The excellent team described here corresponds, interacts, and collaborates with researchers over a remarkable range of disciplines. Our research faculty are frequently invited to speak at national and international conferences and are also invited as visiting scientists to other international high field facilities. Our engineers collaborate with the NMR vendors, transferring technology and advancing capabilities. In addition, they develop unique hardware for the home research laboratories of our collaborators extending the impact of our program beyond the bounds of the Magnet Lab's sites. In Tallahassee, the team works to provide many unique capabilities on our high field magnets including the ultra-wide bore 900, but we are also working hard on future systems, such as the recently funded construction phase of the 36 T Series Connected Hybrid. Even further into the future we hope to be developing capabilities for a 30 T high homogeneity superconducting magnet system.

This team would be pleased to hear from any and all potential users. You can find more about the program at our Web site, http://nmr.magnet.fsu.edu and about the personnel at http://www.magnet.fsu.edu/search/personnel.


*Tim Cross, Director of NMR Spectroscopy and Imaging program*
*cross@magnet.fsu.edu*

**Ashley Blue** began working at the NHMFL in 1993 with the DC Facility as a Taylor Technical Institute CO-OP student. While in technical school, he studied electronics and instrumentation. Later he joined the NMR program as a technical/user support staff member. During this time he gained many years of experience in the maintenance of NMR superconducting magnet systems, including prototype pumped systems from Oxford and Magnex. He also completed his bachelor's degree from Florida State University. His current responsibilities include 900 MHz system operator/administrator and overall NMR cryogenic and user support.
***blue@magnet.fsu.edu***

**Richard Desilets** operates the NMR/EMR machine shop where probes, cavities, and related instrumentation are fabricated. Many NMR and EMR users know him because of the last-minute support he provides to repair or adjust their instrumentation. Many others have used probes that benefited from his first-rate fabrication skills. His projects have included the Low *E* probes for NMR of membrane proteins, the set of narrow bore magic angle probes for materials NMR, and the sub-mm EMR facility. Desilets came to the NHMFL in 2001 with considerable experience in industrial machine shops serving the oil and defense industries, including PGI International and Crane Defense Systems (now Crane Co).
***desilets@magnet.fsu.edu***


**William W. Brey** came to the NHMFL in 1999. Prior to joining the NMR group, Brey had primary responsibility for RF coil design for the Conductus/Varian team that developed the superconductive NMR spectroscopy probe. His graduate work with Thomas Mareci and Raymond Andrew at the University of Florida included the development of new designs for gradient coils. Before his graduate study, Brey worked on the research staff at the University of Texas Health Sciences Center, Houston, where he developed pulse sequences, gradient, and RF hardware for MRI and MR spectroscopy. He also worked as a consulting engineer for Tecmag, Inc., which produces retrofit hardware upgrades for NMR spectrometers. At the NHMFL Brey has continued his work with superconductive probes, guided the commissioning of the 900 MHz ultra-wide bore magnet, and is now developing probes and related technology for NMR on the Series Connected Hybrid magnet that is under development (see related story on page 20).
***wbrey@magnet.fsu.edu***



**Riqiang Fu** earned his Ph.D. from Wuhan Institute of Physics, the Chinese Academy of Sciences, P. R. China, and received a President Award of the Chinese Academy of Sciences in 1992. He worked with Geoffrey Bodenhausen as a postdoctoral research associate at the University of Lausanne, Switzerland, and joined the NHMFL when Bodenhausen's group was moved to Tallahassee in 1994. He has continued working at the NHMFL as a faculty member since 1998. He is currently serving as a chair of the 900 MHz Internal Science Review Committee to oversee scientific research activities on this unique spectrometer. His interests are in NMR, including development of solid state NMR techniques and solid state NMR applications to biological chemistry and materials science. Over the years he has developed many new NMR methodologies suitable for

NMR applications at high fields, such as a broadband decoupling sequence (earned a U.S. patent in 1995), frequency modulated cross polarization for sensitivity enhancements in static and rotating solids, simultaneous frequency and amplitude modulation for heteronuclear distance measurements at high fields, quantitative cross polarization, and so on. His current research interests focus on methodology development for aligned membrane proteins, $^{19}F$ solid state NMR applications in membrane proteins and polymers, and NMR studies in battery materials and fuel cells.
***rfu@magnet.fsu.edu***

of biological solids to aid with solving structure of insoluble proteins in a native environment. Gor'kov has come up with several user RF probes that use specially designed low-E resonators instead of conventional solenoids to minimize the high-frequency electric fields that heat protein samples. This allows users to perform sensitive biological NMR experiments in the high field 900 MHz magnet. Several such probes were built for use at other facilities around the country, including Pacific Northwest National Laboratory.
***pgorkov@magnet.fsu.edu***

ZHEHONG GAN

**Zhehong Gan** graduated in 1984 from Zhejiang University in China and received his Ph.D. in chemical physics from the University of Utah in 1990. After several years of managing solid state NMR and EPR instrumentation at the School of Chemical Science of the University of Illinois Urbana-Champaign, he joined Richard Ernst's group in 1994 at the ETH in Switzerland conducting research in solid state NMR. Since joining the NHMFL in 1998, his research interest has been high field NMR, solid state NMR of quadrupolar nuclei, applications in biological and material chemistry. He has invented magic-angle turning (MAT), satellite-transition magic-angle spinning (STMAS) and more recently indirect detected $^{14}N$ NMR in solids. He also collaborates with numerous groups in North America and Europe using the high field NMR facility at the NHMFL.
***gan@magnet.fsu.edu***

PETER GOR'KOV

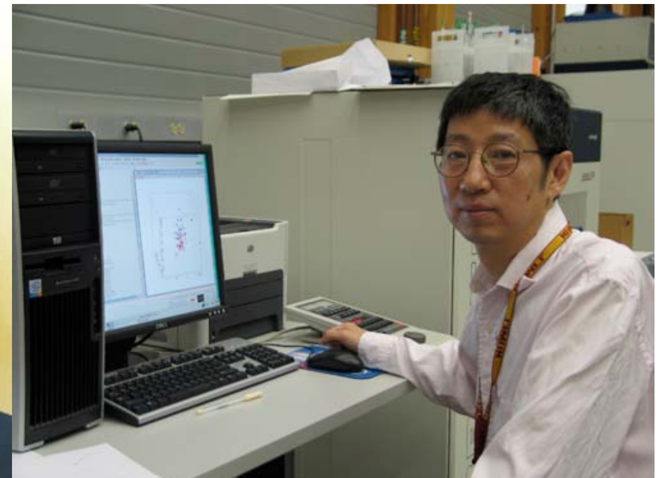
**Peter Gor'kov** came to NHMFL in 1999 from the group of Paul Lauterbur at the University of Illinois in Urbana-Champaign where he designed MRI probes for small animal MRI. At the NHMFL, Gor'kov has designed and built over 25 user probes and accessories for solid state NMR in superconducting and resistive magnets, including RF probes for the 900 MHz UWB magnet. While other labs have acquired high field NMR magnets, the strength of the Magnet Lab's NMR program rests in large part on providing users with unique RF probes that are not available elsewhere. Peter's recent interests focus on developing instrumentation for NMR

VICTOR D. SCHEPKIN

**Victor D. Schepkin** received his Ph.D. from Kazan State University in Russia—the place where magnetic resonance was first discovered in condensed matter by E. K. Zavoisky in 1944. Schepkin's Ph.D. was devoted to the indirect detection of weak sodium MR signals found in solids in the form of impurities or within the neighborhood of impurities. Schepkin's MR imaging experience in the United States includes research at Lawrence Berkeley National Laboratory, in the laboratory of Nobel Laureate Paul Lauterbur at the University of Illinois, Urbana-Champaign, and at the University of Michigan Medical School, department of radiology. His current research interest is in the biomedical arena: MR imaging of apoptosis and developing MR biomarkers for cancer therapy using sodium and proton diffusion MRI. *In vivo* imaging and spectroscopy at 21 T with the 105 mm bore available at the NHMFL opens new horizons for biomedical research. This extraordinary and unique research instrument offers the highest achievable resolution for anatomical MR imaging as well as the highest resolution functional MRI using other nuclei present *in vivo* such as sodium, carbon, potassium, chlorine, and other elements.
***schepkin@magnet.fsu.edu***

**Kiran Shetty** has been part of the instrument development group at the Magnet Lab since 2003. He graduated from Florida State University with a master's degree in electrical engineering in 2003. His graduate work with Frank Gross included developing an algorithm for uplink interference suppression in a Spatial Division Multiple Access (SDMA) based mobile cellular system using wireless adaptive array (Smart Antennas) techniques.

KIRAN SHETTY



FENGLI ZHANG

Shetty joined the NHMFL in time to play a key role in the 900 MHz commissioning phase. He was involved in a number of engineering projects as well as field mapping and analysis, initial user support, and system testing. He is now involved in the testing and implementation of a flux stabilization system to minimize temporal fluctuation in the Series Connected Hybrid under development. In addition to providing user support for NMR experiments in high field magnets he also builds NMR RF probes for different applications.
***shetty@magnet.fsu.edu***

**Fengli Zhang** received his Ph.D. in biophysics from Beijing Medical University. He worked at the University of Kansas, Boston University, and Clark University before he joined NHMFL in 2005. His main responsibility at the laboratory is to manage the solution NMR program. He also collaborates with Rafael Brüschweiler's group to carry out research projects.

His research interests include developing covariance NMR methods and applying them to various NMR areas, such as high resolution NMR protein assignments and structure determinations, studying correlated protein motions by NMR relaxation, and molecular dynamics simulations.
***fzhang@magnet.fsu.edu***

## AMRIS Facility

We regularly publicize the big magnets, fantastic probes and coils, and exciting science in the Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) facility. However, at its core, the most important part of the facility is the technical staff who make the magic happen. These are the unsung heroes who are fixing boards, filling cryogens, cleaning up floods (about 3 inches of water covered the entire facility floor last month after a filter broke!), keeping instrument records, working with vendors, training new users, collecting data, putting multiple instrument time requests together like jigsaw puzzles, doing quality control, running user safety programs, helping write publications (sometimes without authorship), etc. In short, nothing that we do in AMRIS would work without the dedication of our wonderful technical staff. I hope everyone will take the time to read their short bios and to get to know them when the opportunity arises. They are a professional group with outstanding skills who are a great pleasure to work with.

*– Art Edison, AMRIS Director*

BARBARA BECK

**Barbara Beck** has 20 years of experience designing and testing RF coils for MRI. She has built coils for a range of magnetic field strengths, from 0.15 T to 11.1 T, for clinical whole body systems and animal research systems. She has worked in the academic setting as well as the corporate environment. Most recently she has been a part of an NIH Resource Grant (P41 RR16105) to develop array technology and large volume resonators for the 11.1 T, 40 cm clear bore magnet at the University of Florida. Beck has several dozen publications on coil technology and regularly makes presentations at the annual meeting of the International

Society of Magnetic Resonance in Medicine (ISMRM). Her poster, "Wave Behavior in Phantoms at 11.1 Tesla," presented at the 12th annual meeting of the ISMRM in Kyoto, Japan, received a ribbon in the EM Fields, Coils, and Hardware category and her poster "Comparison of Microstrips and Surface Coils at 11.1 T as Building Blocks for Phased Array Surface Coils" presented at the 13th Scientific Meeting of the ISMRM in Miami, received a ribbon in the Engineering category. Beck is currently a senior engineer in the AMRIS facility at the McKnight Brain Institute at the University of Florida.
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GARY BLASKOWSKI

**Gary Blaskowski** received his master's degree in physics from the University of Florida in 1994. He assists users with equipment related to imaging experiments and takes all users through magnet safety. He is responsible for routine maintenance and repair of imaging systems. He also schedules magnet time and confirms magnet usage. He is trained in animal handling, and is available as an imaging consultant. In his free time he enjoys potting and re-potting potted plants.
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KELLY JENKINS

**Kelly Jenkins**, engineering technician, builds and maintains prototype RF coils and provides additional user support through cryogen and NMR facilities maintenance.
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**David M. Peterson** is a senior engineer with over 19 years of radio frequency (RF) experience and 11 years as an engineer in the field. His duties include RF coil design from 1.5 T to 21 T for imaging and spectroscopy and management of the 3 T human imaging facility located in the McKnight Brain Institute. A major focus of his career has been on engineering methods for MRI and RF coil design.

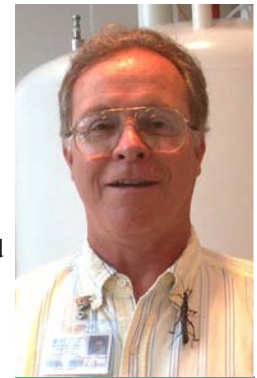
Peterson graduated from Florida A&M University in 1995 with a bachelor's degree in electronics engineering technology. He received his master's degree in engineering from Newport University in California and is currently pursuing a Ph.D. in biomedical engineering at the University of Florida.
***dave@mbi.ufl.edu***

**Daniel Plant** received his B.S. and M.S. in chemistry from the University of Florida under Wallace Brey in 1987. Following stints with GE NMR Instruments and Bruker BioSpin, he settled back in at the McKnight Brain Institute and currently manages six spectrometers used for animal imaging, NMR microscopy, and high-resolution spectroscopy. Dan collected the first high-resolution 3D NMR experiment and holds patents in Multidimensional NMR Spectroscopy. He participated in the first gradient spectroscopy experiments at GE where he helped build the first 3-axis gradient probe for spectroscopy.

His research interests include the microscopy and micro-imaging of marine creatures for their ability to provide simplified models of neural interactions. Targeted contrast agents are also under investigation with a specific interest in isotopic methods.
***dan@mbi.ufl.edu***

**Jim Rocca** is a senior chemist with AMRIS principally responsible for solution NMR applications on the facility's four vertical-bore spectrometers. He also occasionally advises about spectroscopic matters on AMRIS's horizontal-bore imaging instruments. Rocca ensures proper operation of the spectrometers, provides instruction for operators—particularly valuing chances to work closely with graduate students and postdoctoral associates, does a bit of troubleshooting and maintenance, and analyzes samples for users who are not able to provide their own operators.

Prior to becoming an applications specialist with AMRIS (and previously with the university's Center for Structural Biology), Rocca's background was largely in organic chemistry. He received his undergraduate education at the University of Central Florida and graduate education in chemistry at Cornell University and the University of Florida. He has worked in academia, in state and federal governmental laboratories, and in light industry, and has experience in conventional organic synthesis; organo-metallic chemistry; natural products chemistry, especially of insects, high performance gas and liquid chromatography, including pesticide analysis; and infra-red, mass, and NMR spectroscopy. His favorite NMR experiments employ Nuclear Overhauser Effect Difference Spectroscopy.



JIM ROCCA

Rocca enjoys collaborative research opportunities and has recently published with a number of different research groups in *Biochemistry*, the *Journal of Medicinal Chemistry*, *Journal of Magnetic Resonance*, and others. The insect on Jim's shirt in the accompanying picture is a walking stick of the genus *Anisomorpha*. It produces venom that was extensively characterized in work with Aaron Dossey, Spencer Walse, and Art Edison, which should be published soon in *ACS Chemical Biology*.
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**Xeve Silver** received his B.S. in psychobiology and molecular biology from the University of Miami. He spent four years as a senior biological scientist in Dr. Thomas Mareci's UF lab focusing on inductively coupled implantable RF coils and spinal injury related MR studies. Silver now works in the AMRIS facility as the scientific research manager, where he facilitates imaging and animal spectroscopy projects. His interests and duties include imaging protocol optimization and development, end-user training, animal research, cardiac imaging, new and novel imaging techniques, contrast mechanisms, and diffusion based studies. At home, Silver is the father to a two-year-old, a husband, chef, and A/V and computing technologist.
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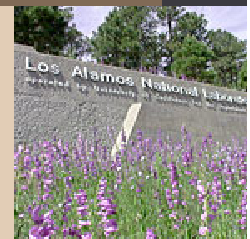
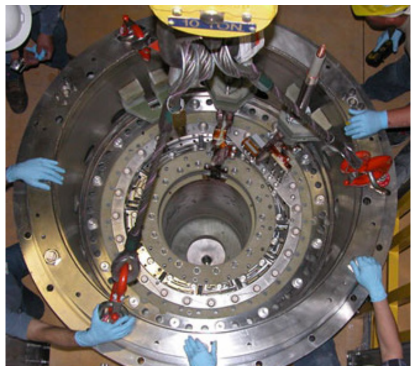
# Pulsed Magnet Achieves 80-tesla Operations




LOS ALAMOS, N.M. – The National High Magnetic Field Laboratory continued its string of firsts this summer when two critical components of the 100 Tesla Multi-Shot magnet program achieved new milestones, including another world record.



The “100 T” – a joint project of the National Science Foundation and the Department of Energy – is a combination of seven coil sets weighing around 18,000 lbs., powered by a 1200 megajoule motor generator, and an insert coil powered by a 4 MJ capacitor bank.

In mid-August, the lab finished commissioning of the outer set of coils. During the commissioning, a peak magnetic field intensity of 35 tesla in an 8-inch bore was reached – a new world record. These energy levels are only achievable because of the unique design of the magnet itself and the availability of the large Los Alamos power source.

“The ability to reach such a high field in such a large volume is an important milestone in developing a 100 T capable magnet,” said Alex Lacerda, associate director for user operations at all thee sites of the Magnet Lab.

Also this summer, the lab’s newly developed pulsed-magnet prototype survived multiple shots at 80 tesla. Testing of the prototype is designed to establish the limits of the present generation of pulsed-magnet technology by pulsing the coil to destruction.

“Both achievements are great news for the Magnet Lab and huge landmarks for the lab’s technical and engineering expertise,” said Magnet Lab Director Greg Boebinger. “This kind of success requires not only first-rate engineering, but also first-rate craftsmanship by our coil winders, machinists, welders and magnet operators throughout the Magnet Lab.”

The 80-tesla model coil sets a new standard for high-performance pulsed magnets and will be very useful in determining operating parameters for the 100-T program. Several other labs worldwide have attempted to deliver similar systems without success.

Development of the 100 T requires close coordination between the Tallahassee, and Los Alamos sites of the lab. Team members include: Chuck Swenson, pulsed magnet team leader; Bill Sheppard, technical winding; Todd Adkins, tooling CAD; Scott Bole, engineering manager; Mark Collins, coil machinist; Mike Gordon, bank operations; Steve Kenny, magnet CAD; James Michel, technical winding support; Ed Miller, technical winding; Mike Pacheco, component fabrication and test setup; Alan Paris, bank operations; Ken Pickard, coax leads and material coordination; Dwight Rickel, magnet testing; Josef Schillig, capacitor bank design; Robert Stanton, welding; and Jeff Martin, diagnostics.

**Pulsed-magnet program on the right track**

To build on the success of the pulse program, the lab in July announced it would consolidate some of the pulsed-magnet development at Los Alamos, with team leader Swenson moving from the Tallahassee campus to New Mexico.

“I believe the Magnet Lab will be strengthened by this transition,” said Swenson. “There will be more opportunities for cooperation and mutual support.”

Lacerda said Swenson and collaborators at both sites have dramatically improved pulsed-magnet technologies, making progress that hasn’t been seen in a decade.

“Chuck Swenson is key to the expansion and success of the pulse program,” said Lacerda. “Working more closely with the Los Alamos engineering team will strengthen the collaboration to the benefit of the continued development of pulsed-field magnets.”

**Opening a new window to users**

Once completed, the magnetic field of the 100 Tesla Multi-Shot system will provide routine non-destructive access to stronger thermodynamic effects than any other thermodynamic variable but temperature. It will provide magnetic fields significantly above current state-of-the-art pulsed magnets for pulse durations of approximately 10 milliseconds – which is about 1,000 times longer than the “single turn” system or explosively driven high-magnetic-field apparatus.

It’s expected to have a profound impact on investigating a wide range of scientific topics, from how materials behave under the influences of very high magnetic fields, to the microscopic behavior of phase transitions.

# NEWS from the DC Field Facility

**Bruce Brandt, Director**

The tunneling of electrons from a sharply pointed metal tip into the surface of a material provides useful information about the density of states available to the electrons in the material. Furthermore, the delicacy and elegance of the instruments needed appeal strongly to people who design and buy research instrumentation. The Magnet Lab, after years of discussions, finally has a tunneling technique available for users of the DC High Field Facility. A probe for point contact spectroscopy has been developed by a group led by Amlan Biswas of the University of Florida and including Sung Hee Yun of U.F., and Bing Liang and Richard L. Greene of the University of Maryland. Their work was funded by the In-House Research Program and fulfilled all the goals of that program by producing high quality research, training students, and developing new instrumentation for users. Their results are described in the following article.

## Point contact spectroscopy of anisotropic superconductors at high magnetic fields.

Sung Hee Yun, Amlan Biswas, UF
Bing Liang, R. L. Greene, UMD

Tunneling spectroscopy has proven to be a powerful technique for studying the electronic density of states (DOS) near the Fermi level in conventional BCS superconductors. However, the short coherence length in high-$T_c$ cuprate superconductors (HTSC) means that tunneling spectroscopy, which probes the surface density of states, can provide information for only a few atomic layers beneath the surface. This imposes strict requirements for the quality of the sample surface. The best results are obtained on samples that have been cleaved *in-situ* before forming the tunnel junction. Hence, the most significant tunneling data have been obtained on BSCCO, which has a very convenient cleavage plane. This leaves out the large set of other cuprates, which do not share this particular property. For such materials, it is useful to construct tunnel junctions using the native insulating layer formed on the cuprate as the insulating tunnel barrier. This can be done either by forming planar tunnel junctions or by performing point contact spectroscopy. Significant progress has been made in the fabrication of planar and point contact junctions and these experiments have given invaluable information about the DOS of HTSCs and other new superconductors.

Point contact spectroscopy (PCS) is similar to scanning tunneling spectroscopy, in the sense that the current injection occurs between a sharp tip and the sample. However, in PCS the tip is actually in physical contact with the sample. PCS is also less susceptible than scanning tunneling spectroscopy to mechanical vibrations, which is an important factor to consider when choosing a measurement method for the water-cooled magnets in the DC High Field Facility at the Magnet Lab.

Why do we need to perform PCS at high magnetic fields? An explanation for the phenomenon of high-$T_c$ superconductivity has to deal with the underlying pairing mechanism and why it happens at such high temperatures. Hence, one needs to understand the original state that was destabilized to give rise to superconductivity. We will call this non-superconducting state, the "normal state". Hence, it is essential to understand the normal state of HTSC in order to

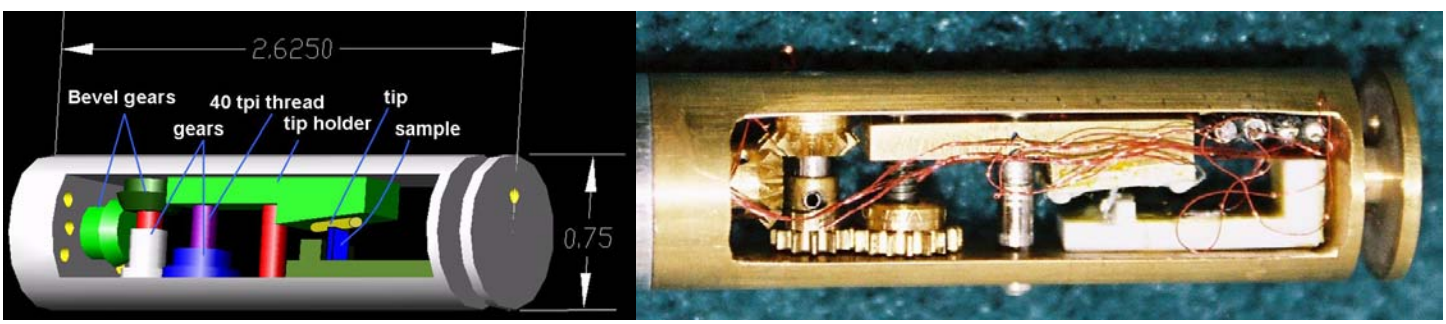



**Figure 1.** The mechanism for forming the point contact junction for tunneling into the a-b plane of cuprate superconductors. Rotation of a shaft extending from room temperature to the probe head is transferred by the bevel and straight gears to rotation of the 40 thread per inch screw that pushes on one end of the tip holder and presses the tip against the sample.

explain the mechanism behind the high critical temperatures. The $T_c$ (about 25 K) and upper critical fields (about 10 T at 2 K) of *n*-doped cuprates are significantly lower than *p*-doped cuprates. Hence, it is possible to study the normal state of these materials at low temperatures at the NHMFL in Tallahassee[2].

The usefulness of PCS for studying superconductors is greatly enhanced by a theory developed by Blonder, Tinkham and Klapwijk (BTK), in which they discuss the dependence of the I-V (current-voltage) characteristics of a junction between a superconductor and normal metal on the strength of the barrier between the electrodes (denoted by a dimensionless number Z)[1]. This theory enables us to extract information from PCS data. It also suggests that for large barrier strengths (Z >> 1), a point contact junction behaves similarly to a tunnel junction.

We have constructed a PCS probe for the 32 mm bore DC field magnets and have used it for measurements up to 33 tesla at temperatures down to 1.5 K. The first requirement was a probe design that would fit into the small space in the cryostat in the magnet bore, increase the resonance frequencies of the tip-sample approach mechanism, and improve the stability of the point-contact junction. Since cuprates are highly anisotropic materials, tunneling and point contact spectra show a strong dependence on the direction of tunneling. For our experiments we need to tunnel into the a-b plane and also apply a magnetic field perpendicular to the a-b plane. Such a configuration adds a further complication to our probe design because we now need to be able to move the tip with respect to the sample, perpendicular to the magnetic field. Such a configuration was achieved by using bevel gears to change the direction of rotation (Figure 1). Experiments were performed at constant magnetic field, which reduced the eddy current heating of the brass probe. For finer control over the junction resistance, a worm-gear arrangement (1:96 ratio) was used at the top of the probe.

Specialized electronics and software for data acquisition are also essential for PCS. The PCS data needs to be presented as plots of dI/dV vs. V (I and V are the junction current and voltage respectively). dI/dV is approximately proportional to the DOS for low voltages (~20 mV). A digital voltmeter monitored the junction voltage as it was slowly ramped by a function generator. One lock-in amplifier/detector supplied a sine wave that was used to modulate the junction voltage. That lock-in measured dI/dt through a resistor in series with the junction, while a second lock-in measured dV/dt across the junction. The two lock-in signals and the junction voltage were recorded by the NML Data Acquisition[3] program which calculated dI/dV = (dI/dt)/(dV/dt) and plotted it against V.

A dI/dV vs. V curve for a point-contact junction between the n-doped cuprate $Pr_{2-x}Ce_xCuO_4$ (PCCO, x = 0.15) and a Pt-Rh wire taken at T = 1.5 K and H = 0 is shown in Figure 2(a). The data clearly reveal the superconducting gap, and the value of the gap shows excellent agreement with published data[2]. Figure 2(b) shows the PCS data at 1.5 K in a field of 31 teslas. The data show that the pseudogap exists even in a field of 31 T. Figure 2(c) shows the variation of the point contact spectra from 0 T to 23 T. The

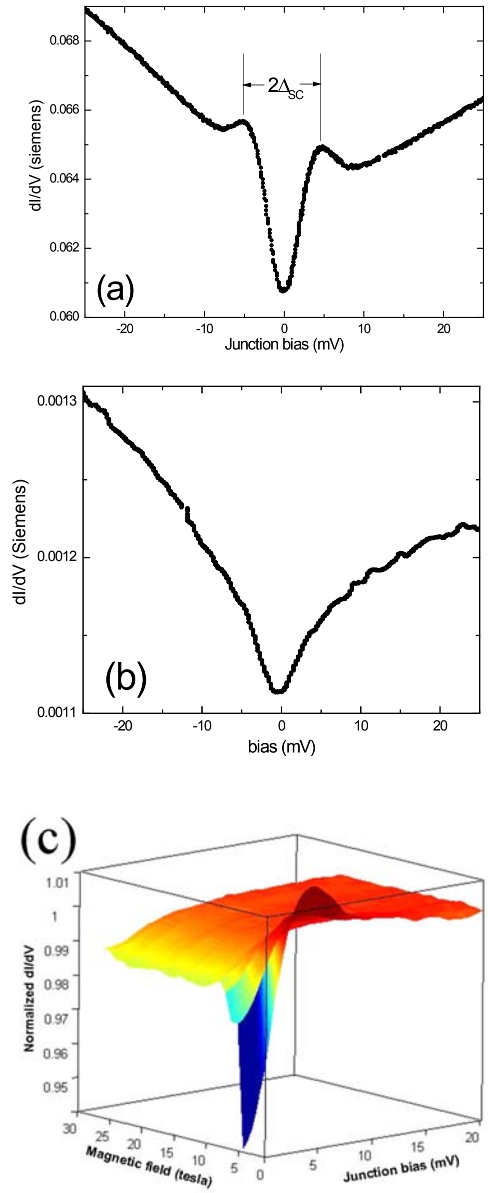



**Figure 2**. Point contact spectra of a junction between PCCO and a Pt-Rh tip taken at 1.5 K in a field of (a) 0 T and (b) 31 T. (c) Evolution of the point contact spectra with magnetic field.

PCS probe can be used for high field studies of the density of states of new superconducting systems such as heavy fermion systems. It can also be used to perform point contact Andreev reflection experiments on ferromagnetic materials.

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3 S. T. Hannahs, Written in *LabVIEW 1.0* in 1989 and evolving ever since.

The University of Florida and the MagLab are very pleased to have recently added another strong NMR scientist to our faculty. Sergey Vasenkov is a new assistant professor in the Department of Chemical Engineering. His specialty is the application of various computational and experimental techniques, such as pulsed field gradient NMR, to study molecular transport in a variety of materials, including lipid membranes. Vasenkov's expertise provides a very nice complement to existing strengths in AMRIS and the MagLab in membrane protein structure, membrane dynamics studies, and diffusion measurements in biological tissue. He completed his Ph.D. in physics and mathematics at the Institute of Chemical Kinetics and Combustion (Novosibirsk) in 1994. Vasenkov was a postdoctoral fellow at Lawrence Berkeley Laboratory, University of California, Berkeley from 1995 to 1998 and was a member of the teaching and research staff of the Department of Physics and Earth Sciences at the Leipzig University from 1998-2005. He was awarded the Habilitation degree (i.e. advanced Doctorate degree, which includes a lecturing qualification) by Leipzig University in 2003.

## Towards NMR Studies of Translational Dynamics in and around Nanosized Functional Domains of Lipid Membranes

S. Vasenkov, University of Florida

Experimental evidence collected over the last several decades shows that biological membranes of eukaryotic cells are inhomogeneous on various length scales. It has recently been suggested that several types of membrane heterogeneity such as protein-lipid complexes and domains, which are also known as rafts, are used by cell membranes as platforms for many vital functions including signal transduction and sorting of membrane components.[1-3] There is also growing experimental evidence suggesting that lipid rafts actively participate in the processes of assembly, replication and entry of many viruses.[4,5] Lateral diffusion of signaling molecules and proteins in the heterogeneous landscape of cell membranes can be the rate-controlling step in these processes. Hence, changing the effective diffusion rates by creating structural heterogeneity such as rafts can be the leading mechanism used by cells to regulate the rates of cellular processes in a broad range.

Most recent experimental evidence suggests that only very small (around 100 nm or smaller) and possibly also unstable rafts can form in non-activated cells.[3,6-9] As a result of these findings the focus of current studies on rafts is shifted towards smaller length scales (around 100 nm), which are believed to be comparable with sizes of lipid rafts in resting cells. Until now studies of the structure of and dynamics in lipid membranes have mostly been carried out by using microscopy techniques, which are based on detection of dye-tagged or gold-tagged molecules. The invasive nature of these techniques presents a major obstacle on the way of resolving fundamental questions concerning existence, functions and properties of lipid rafts.

The deficiencies of the current situation with monitoring translational dynamics on the length scale of sizes of raft-like domains can be overcome by introducing a novel experimental option, viz. PFG NMR with ultra-high magnetic field gradients, to the membrane research. Using this method, diffusion studies of large ensembles of membrane components in lipid membranes on the length scale between ~100 nm and several micrometers will become possible. This method allows simultaneous monitoring of the diffusion statistics of molecular ensembles, which are many orders of magnitude larger than those used in single molecule (particle) tracking. This results in a very high statistical accuracy of the diffusion data.

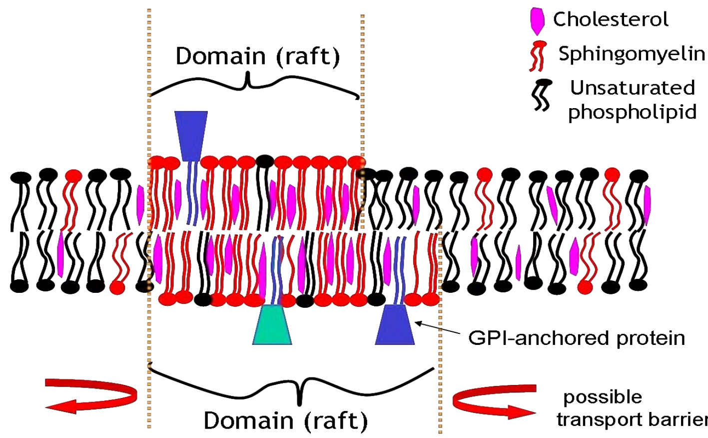


**Figure 1.** Schematic presentation of a lipid membrane.

PFG NMR is based on the dependence of the Larmor frequency, which can be understood as the frequency of the rotation of spins around the direction of the applied magnetic field, on the amplitude of the applied field.[10-13] Superimposing a large constant magnetic field by an inhomogeneous field (i.e. so-called magnetic field gradient pulses), the positions of the spins can be labeled by the Larmor frequency and hence also by the phases accumulated due to the rotation with the Larmor frequency in the local field. The dependence of the accumulated phase on the spin position is of crucial importance for the measured PFG NMR signal (spin echo). If the molecules, where the spins are located, do not change their positions during the effective diffusion time (t), the signal will retain its maximum value. However, if there was a displacement of the molecules during this time interval, the measured spin echo signal will loose part of its value. Assuming that the diffusion process may be described by the laws of normal (i.e. Fickian) diffusion with an effective diffusivity (D) the signal attenuation (Ψ) may be presented as[14]

$$\Psi = \exp(-q^2 tD), \qquad (1)$$

where $q = a\gamma\delta g$, $\delta$ is the duration of the applied gradient pulses with the amplitude g, $\gamma$ denotes the gyromagnetic ratio and a is a proportionality constant, which depends on a PFG NMR sequence.

Recent advances in PFG NMR technique, which allow monitoring molecular diffusion on submicrometer length scales, open a direct way to study relation between structure and transport in various nanostructured porous materials.[15] In particular, we have recently shown that direct PFG NMR measurements of molecular diffusion in fluid catalytic cracking (FCC) catalysts can be used to find new routes of optimization of these materials with respect to transport of reactant and product molecules.[16,17] In the next section a brief overview of these studies will be given. These results provide a solid basis for extending PFG NMR diffusion studies to protein-lipid membranes under the conditions of application of ultra-high (up to 30 T/m) magnetic field gradients. Preliminary results of such studies will be presented in the third section of this paper.

The PFG NMR measurements reported below were carried out using the home-built PFG NMR spectrometer Fegris NT operating at a $^1$H resonance frequency of 400 MHz. The main limitation of these studies is related to a low signal-to-noise ratio. This limitation will be overcome in a future research at AMRIS by using 750 MHz spectrometer.

## *PFG NMR studies of diffusion in fluid catalytic cracking (FCC) catalysts*

Typically, each particle of a formulated FCC catalyst possesses a complex system of pores consisting of micropores located in zeolite crystals and of macro- and mesopores located in the so-called "matrix", which surrounds the crystals.[18] PFG NMR diffusion measurements have been performed at different temperatures and for the whole range of molecular displacements, which are essential for a detailed understanding of molecular transport in FCC catalysts.

As an example of the PFG NMR diffusion studies performed for the extremely small molecular displacements Figure 2 shows measured dependencies of the effective diffusivities of guest molecules (n-octane) on the root mean square displacements in USY zeolite and in the parent ammonium-ion exchanged zeolite Y.[17] The former zeolite is the main, catalytically active component of particles of FCC catalysts. It was produced by a specially-designed steaming of the latter zeolite. Similar steaming is also used in a large-scale production of FCC catalysts. The diffusivities in Figure 2 were obtained from the corresponding slopes of the PFG NMR attenuation curves, which were found to comply in all cases with Eq.1. The data in Figure 2 indicate that the measured diffusivities decrease with the increasing root mean square displacement. It is seen that in the semilogarithmic presentation of Figure 2 the shape of the dependencies for any particular sample remains essentially the same at different temperatures. This behavior can be attributed to the restriction of the diffusion of guest molecules by the size of the zeolite crystals and/or crystal agglomerates.[11]

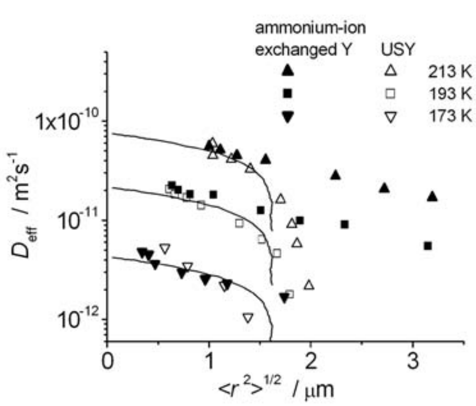


**Figure 2.** Dependencies of the effective diffusivities on the mean square displacements measured for n-octane by PFG NMR (points) and those obtained by the dynamic Monte Carlo simulations (lines) for a cubic lattice with a size 2.3×2.3×2.3 μm$^3$. The boundaries of the simulation lattice were assumed to be impenetrable for diffusing molecules.[17]

In the considered situation the molecular displacements are so large, that during the diffusion time many molecules can reach the crystal (or crystal agglomerate) external surface. Once they reach the surface, the molecules are often reflected back to the inner part of the crystals due to either a large difference between the free energy in the intracrystalline volume and in the surrounding gas phase, or a high concentration of structural defects, which are expected to exist on the external surface of zeolite crystals. Figure 2 indicates that the mean separation between the restrictive boundaries (i.e. the mean size of the zeolite crystals and of the crystal agglomerates) is different in different samples. This is demonstrated by the observation that the shape of the dependencies in Figure 2 is different for the ammonium-ion exchanged Y and USY samples.

The results reported above show that it is feasible to monitor anomalous (i.e. restricted) diffusion in complex system on the submicrometer length scale. These results have proved to be essential for a clarification of the role of various mechanisms of diffusion in transport limitations arising during catalytic reactions under typical FCC conditions.[16,17]

## *Extending diffusion studies by PFG NMR with ultra-high gradients to lipid membranes*

Figure 3 shows examples of the measured $^1$H PFG NMR attenuation curves in oriented multibilayer stacks on glass plates. The multibilayer stacks have been prepared for a canonical lipid raft mixture (Cholesterol/brain sphingomyelin/1,2-dioleoyl-sn-glycero-3-phosphocholine(DOPC) = 1/1/1) following the standard procedure (see, for example, Ref.19). It consists of a deposition of dry films of a lipid mixture on thin glass plates (5×5×0.08 mm$^3$, Marienfeld GmbH, Germany), which is followed by hydration with $D_2O$ by exposing the films to the water vapor at 100% humidity. The glass plates with bilayer stacks were oriented in NMR tubes at the "magic" angle (i.e. angle of 54.7° between the dipole moment of lipids and the direction of the external field $B_0$). Such bilayer orientation allows decreasing the disturbing influence of the dipole-dipole interaction on diffusion measurements.[19] The degree of the lipid orientation was controlled by $^{31}$P NMR. The maximum amplitude of the applied field gradients was around 25 T/m.

The diffusion measurements were performed by using the stimulated echo sequence, if not indicated otherwise. Fitting attenuation curves by the equation of the type of Eq.1 with one exponential term (single diffusivity) or two weighted exponential terms (two different diffusivities) shows that for the temperatures lower than or equal to around 297 K the two-exponential fit produces better results than the one-exponential fit (Figure 3). At the same time, for the temperatures higher than 297 K it was sufficient to use single-exponential curves (viz. Eq.1) to fit the experimental data satisfactorily. The data in Figure 3 suggest that the diffusivity(ies) at each temperature used were essentially independent of the diffusion time in the measured range. This is demonstrated by a good agreement between the attenuation curves measured for different diffusion times and under otherwise

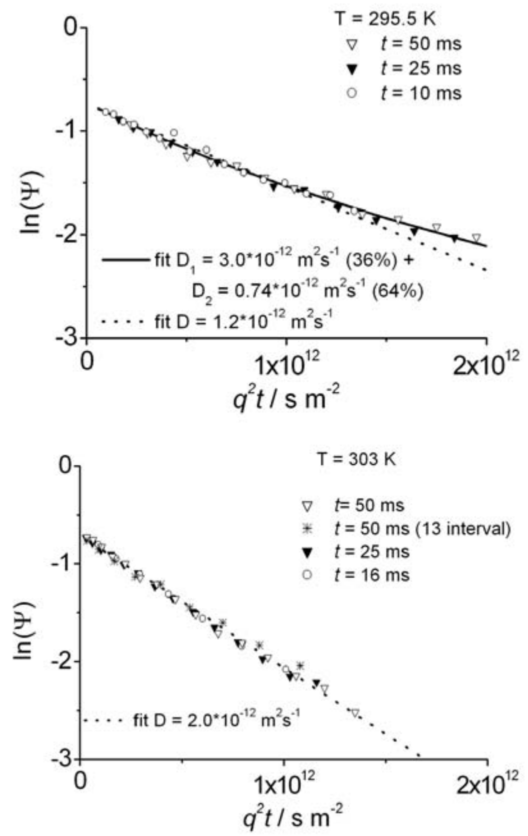


**Figure 3.** 1H PFG NMR spin-echo attenuation curves measured in oriented multibilayer stacks on solid supports. Dotted lines show the results of fitting by using Eq.1. Solid line is a result of fitting by a modified Eq.1 where instead of one single-exponential term, a sum of two such terms with different diffusivities is used.

the same conditions. However, significantly better signal-to noise ratio that would allow measurements in a much larger range of the signal attenuation is necessary in order to get detailed information on diffusion. The diffusivities obtained by using the two-exponential fit were assigned to those in the two types of co-existing fluid domains (i.e. the liquid-ordered and liquid-disordered domains) observed in such systems by fluorescence microscopy.[20,21] The values of these diffusivities were found to be in a satisfactory agreement with the corresponding diffusivities measured by fluorescence correlation spectroscopy and by PFG NMR with the conventional gradient strength (≤10 T/m) in similar systems.[22,23] The results reported above prove the feasibility of diffusion measurements in lipid membranes with the experimental setup that would allow using commercially-available PFG NMR probes capable of generating ultra-high gradients.

## *Conclusion*

In our future research we will use PFG NMR with ultra-high gradients for studies of diffusion of lipids, receptors and proteins in lipid bilayers on the length scale comparable with the size of raft-like domains. NMR detection of receptors and proteins will most likely require isotopic labeling. 750 MHz NMR spectrometer located in AMRIS is optimized for such studies because it combines advantages of high magnetic field resulting in a high signal-to-noise ratio with ultra-high gradients that allow probing extremely small displacements and slow diffusion. The former is important because membrane samples are usually very small. The latter is of even larger importance due to the requirement to probe displacements, which are as small as the raft size. Using membranes reconstituted in porous alumina we plan to study how alteration of membrane composition changes lipid and protein dynamics on the nanoscale. Our expectations of a high significance of such studies are supported by a recent observation showing that diffusion measurement can be used as a very sensitive test for the formation of protein-lipid, protein-protein and receptor-ligand complexes in lipid membranes.[24]


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# Access to science education:
## *REU, RET programs wrap for summer*

**Pat Dixon, director of the NHMFL Center for Integrating Research and Learning (CIRL)**

As the summer draws to a close and a new school year begins, educational programming changes direction from REU and RET programs to school and lab-based outreach and expansion of programs to include workshops for undergraduate and graduate students working at the lab. Work does not stop on summer programs, however, and drawing on the success of summer 2006, we are planning even more activities for students of all ages.

Both the REU and RET programs ended with well-attended poster sessions that were covered in the local media. Lab scientists were unanimous in their praise for students and teachers and the contributions that they made. For example, Mike Davidson commented that the work done by REU students Lyna Fredericks from the University of the Virgin Islands and Xiomaris Cotto from the University of Puerto Rico "made a contribution to their education and research efforts in live cell imaging."

Bill Brey worked with student Shiela Jones from Pacific Lutheran University, Ramchand Maharaj, a high school teacher from Margate, Fla., and Tracy Doyle, a high school teacher from Pittsburgh, Pa. The teachers and student programmed imaging software that contributed to the work being conducted on the Series Connected Hybrid.

Programs such as REU and RET are dependent upon the advice, expertise, and mentorship of Magnet Lab faculty and staff and this year's mentors went above and beyond to make this a memorable summer: Bill Brey, Jim Brooks, Jim Cao, Irinel Chiorescu, Mike Davidson, Mabry Gaboardi, Bob Goddard, Ke Han, Munir Humayun, Alex Lacerda, Chuck Mielke, Roy Odom, Tom Painter, Eric Palm, Alexei Souslov, Kevin Storr, Stan Tozer, Johan Von Tol, and Vivien Zapf.

*SciGirls*, a camp for middle school aged girls interested in science, was a huge success and resulted in a great deal of interest for vacation camps and summer camps. Funded through a grant from Dragonfly TV, girls participated in two weeks of science activities visiting area laboratories and science facilities. All partners agree that this was an enormous success and are committed to continuing programs that encourage young women to pursue high level courses in high school and science as a college major.

Center educators believe that it's never too early to begin nurturing children's natural curiosity in science and are working with the local public library to create a "Science and Parents Program" that encourages parents to do simple science activities with their pre-school aged children.

Plans for the coming school year include:

- Expansion of the Comet Tales program to reach students in grades K-4, and continuation of the program in grades 6-9. Based on NASA's recently completed Stardust Mission, the inquiry based activities are designed to build excitement into the science classroom while at the same time translating research conducted at the Magnet Lab;
- Continuation of our popular classroom outreach program;
- Development of online resources to extend CIRL's outreach;
- Working with area teachers on an ongoing basis to enhance inquiry-based science in the classroom;
- Educational research and presentations at national conferences; and
- Continuation and expansion of partnerships with university departments.

# NMR Development for Series Connected Hybrid Involves Users, Teachers and Students

by William W. Brey

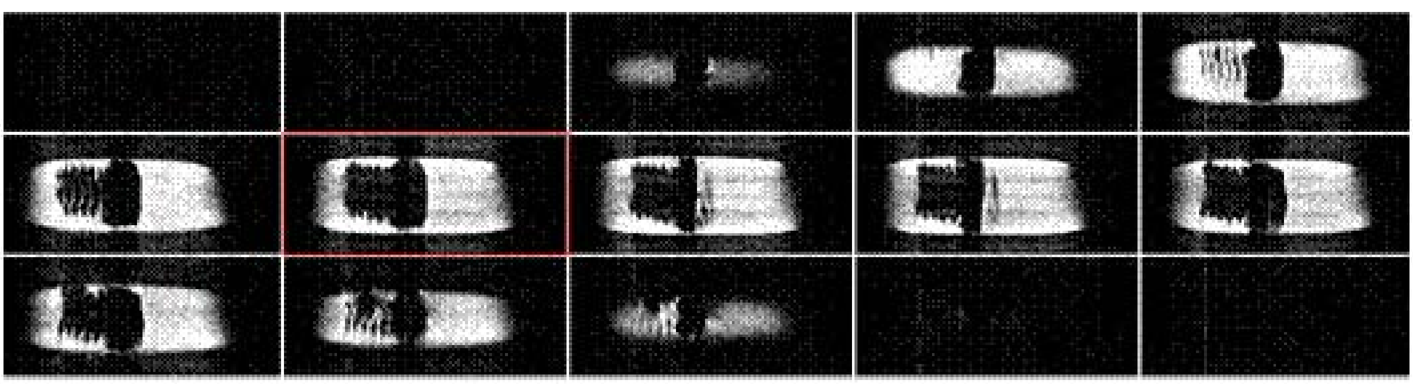
Although the advent of the Series Connected Hybrid is still years away, the lab's Nuclear Magnetic Resonance program staff and scientists are already preparing to take advantage of this novel magnet.

The SCH is a revolutionary step forward for NMR in chemistry, biology and materials science. It will open the vista of magnetic field strength from 25 to 36 T to NMR and other experiments that require a more uniform and stable field than what is available in the 45 T Hybrid. It will also be capable of running experiments that require more than 8 hours at uninterrupted full field, and of sweeping from zero to full field. The scientific program includes the analysis of proteins, nucleic acids, catalysts, conductors and semiconductors. The SCH also will be used for the characterization of electronic, magnetic, optical, and superconducting materials. The lab recently completed the design phase, and expects to soon receive word about a grant for the construction phase.

Tracy Doyle and Ramchand Maharaj, teachers in the lab's six-week Research Experiences for Teachers program, explain their work to Jim Brooks, an FSU physics professor and director of the Condensed Matter Science-Experimental program at the lab, during a poster session.

The SCH will be the first of a new class of more efficient hybrid magnets that will one day allow the Magnet Lab to offer more days of magnet time without increasing operating expenses — an important consideration in these times of high fuel prices and concern about the environment.

SCH project co-Principal Investigator Tim Cross is working with the NMR program's Zhehong Gan, Bill Brey and Kiran Shetty to ensure that the most exciting science is supported by the best instrumentation. Probe and radiofrequency technologies are just as important as magnetic strength for NMR applications. In fact, a spectrometer for testing new instrumentation and techniques for NMR in DC magnets is set up and running in C210. Efforts toward those goals began in earnest this summer in Tallahassee, and involved users, teachers and students.



**Multiple Transverse Images of a Vinyl Screw Immersed in Water Acquired at 7 T.**
These images were acquired at a resolution of 50x50x370 μm using a spin-echo pulse sequence written by Tracy Doyle and Ram Maharaj during their summer research experience at the Magnet Lab. The images have enough detail to display water signals in the treads and head of the screw. The pulse sequence was implemented on a Tecmag Discovery console equipped with a standard 5-mm NMR spectroscopy probe having triple-axis gradients. The 7-T superconducting magnet used in this effort serviced as a workable surrogate for the 25-T Keck magnet. Future studies will utilize these pulse sequences to implement the first MR imaging applications on the Keck magnet.

Magnet Lab users Lucio Frydman and Boaz Shapira from Israel's Weizmann Institute have borrowed concepts from ultrafast magnetic resonance imaging to make it possible to acquire an entire 2D NMR data set in a single scan. In addition to the great reduction in experiment time, their approach makes possible new and more robust NMR experiments insensitive to the field fluctuations and inhomogeneity of resistive and hybrid magnets. They are working with Gan, Brey and Shetty to implement this technique at the Magnet lab. Shapira visited Tallahassee in July to test the latest techniques in the Keck 25-T resistive magnet.

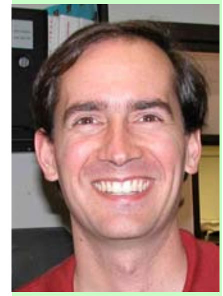
Sam Grant, who joined FSU's Biomedical Engineering program in January as an assistant professor, plans to use the unequaled sensitivity and contrast possible with the SCH for NMR microscopy of cells and biological tissue. And high school physics teachers Tracy Doyle and Ramchand Maharaj from the Research Experiences for Teachers program spent their time at the Magnet Lab this summer developing a suite of MRI sequences that can be used next on the Keck and eventually on the SCH.

Although the field fluctuations of the SCH will be smaller than the other DC magnets, they are still a problem for NMR. Control systems expert (and nuclear quodrupole resonance spectroscopist) Jeff Schiano of Penn State is working with the Brey and Shetty to quiet the anticipated temporal fluctuations of the SCH field. Schiano's graduate student Ming Li spent the summers of 2005 and 2006 in Tallahassee developing and testing digital control algorithms that have already tripled the performance of the Magnet Lab's "flux stabilizer." PSU senior Jenna Samra joined Li in Tallahassee for part of this past summer, and has written up her project as an honors thesis. She plans to be back next summer to continue her work as a master's project.

## MAGNET TECHNOLOGY AT A GLANCE

- **RESISTIVE magnets require both electricity and cooled water while being used. *Advantages:* Capable of reaching higher fields than superconducting magnets. *Disadvantages:* Cost of electricity to run the magnets, amount of power required is limiting.**
- **SUPERCONDUCTING magnets require little or no electrical power to run once they are brought up to full field. *Advantages:* Lower operating costs. *Disadvantages:* Strength of field limited by properties of superconducting materials.**
- **HYBRID magnets combine resistive and superconducting technology, taking advantage of the strengths of each. Most of the magnet's weight and volume use lower-cost superconducting coils. Resistive coils are used only in the small high-field region. The SCH takes this approach and series-connects the coils, substantially reducing the magnetic field ripple and extending the range of experiments that can be performed.**

# PEOPLE IN THE NEWS

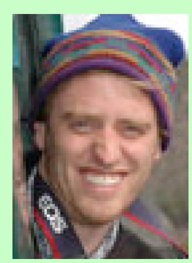


Scott Baily

**Scott A. Baily** is a new postdoc at the Pulsed Field Facility, shared with Magnetospheric Plasma Analyzer-Superconductivity Technology Center). He received his B.S. in physics from University of California San Diego. In 2003 he completed his Ph.D. at University of Illinois Urbana-Champaign, studying the anomalous Hall effect. Between 2003 and 2006, he held a National Research Council Fellowship at Air Force Research Laboratory, Kirtland, N.M., where he studied transport properties of chalcogenide glasses. At Los Alamos, he will focus on transport measurements of high temperature superconductors.

Lili Cheng

**Lili Cheng** joined the NHMFL in August 2006 as a new postdoc working with Scott Crooker to study noise processes in magnetic solid state systems, mainly the thermal magnetization fluctuations in ferromagnetic thin films, by Faraday-rotation noise spectroscopy. She received her B.S. at University of Science and Technology Beijing and completed her Ph.D. at Columbia University. Her doctoral thesis was on the materials-based control of ultrafast magnetization relaxation in ferromagnetic thin films. Her research interests include ferromagnetic thin film deposition and characterization, ultrafast magnetization dynamics, and magneto-optical spectroscopy.



Andrew Christianson

**Andrew Christianson**, who did his graduate work at the lab's Pulsed Field Facility in Los Alamos, has been named a Clifford G. Shull Fellow at Oak Ridge National Lab. His appointment, together with that of Wei-Ren Chen, is the first under the Shull Fellowship program, established by ORNL to recognize Shull's pioneering work in neutron scattering. The goal of the fellowship is to attract new scientific talent to ORNL for the development of its neutron science program. The selection committee looked for candidates with exceptional ability who were capable of developing innovative research programs and who showed the promise of outstanding leadership.

While at LANL, Christianson worked under the direction of Alex Lacerda, the associate director of user operations at all three sites.

**Frederik Wolff Fabris** has accepted a postdoctoral fellowship at the lab's LANL branch working with Vivian Zapf. Fabris received his bachelor's (1998), master's (2000) and doctoral (2004) degrees in sciences from the Physics Institute of the Universidade Federal do Rio Grande do Sul, Brazil, where he studied the granular effects and the chiral ordering effects in superconductors and magnetic systems by measuring magnetization, electrical resistivity and Hall effect. He moved to Belgium in 2005 to work as a postdoc researcher at the Supratecs group (Université de Liège), where he performed thermal transport and magnetocaloric experiments in superconducting foams and multiferroic compounds. At LANL, Fabris will be investigating the Bose-Einstein picture into antiferromagnetic quantum spin systems by using the experimental facilities (magnetization, magnetocaloric effect, specific heat and dilatometry) at milikelvin temperatures and high-magnetic fields available at Magnet Lab. Fabris also plans to study the increasing frustration and disorder in strongly correlated bosonic systems, which could allow observation of the transition from a Bose-Eintstein condensate state to a Bose glass state.

**Sonia Francoual** began postdoc work at Los Alamos National Laboratory this June. Supervised by Neil Harrison and Alex Lacerda, her research aims at investigating the magnetic field-versus-temperature phase diagram of the $URu_{2-x}Re_xSi_2$ heavy fermion compound performing magnetization, resistivity, specific heat, thermal expansion and magnetostriction measurements at high magnetic fields and at low temperatures on the pulse magnets at NHMFL, Los Alamos and on the 45T hybrid magnet at NHMFL, Tallahassee.

Francoual holds a PhD in physics awarded in April 2006 by the Joseph Fourier University. Her research work was performed at the Laboratoire de Thermodynamique et de Physico-chimie Métallurgiques (LTPCM) in St Martin d'Hères, France and at the Max von Laue – Paul Langevin Institute (ILL) in Grenoble, France under the supervision of Marc de Boissieu (LTPCM) and Roland Currat (ILL). The PhD thesis dealt with the study of phonons and phasons in icosahedral quasicrystals and their periodic 1/1 approximants using inelastic neutron scattering, inelastic x-ray scattering, x-ray intensity fluctuation spectroscopy and x-ray diffuse scattering techniques.

**Geoffrey Klein**, most recently a postdoctoral fellow in the lab's Ion Cyclotron Resonance program, began a position as assistant professor of chemistry this fall at Christopher Newport University in Newport News, Va. He graduated with his Ph.D. in the fall of 2005 and has done research as both a graduate student and postdoctoral fellow at the Magnet Lab for more than five years. His major area of focus was in the field of "Petroleomics," the study of all components in crude oil. He plans to continue his work in the analysis of complex mixtures as well as start the analytical chemistry program at CNU.

**Rick Page**, a graduate research assistant and four-year veteran of the Magnet Lab, was recently awarded an American Heart Association Predoctoral fellowship. The fellowship supports his research on the potassium transport protein KdpC. His work seeks the molecular structure of KdpC in an effort to determine how the protein functions. KdpC is part of a three-protein complex, the Kdp complex, which uses ATP as a power source for importing potassium ions into cells.

The Kdp complex is considered a "P-Type ATPase" and is similar to a number of other protein complexes in the same family. The P-Type ATPase family of proteins is critical to maintaining the proper balance of ions within cardiac muscle tissue.

Under the supervision of NMR Spectroscopy and Imaging Program Director Timothy Cross, Page hopes that by finding the structure of KdpC, more can be learned about how ions are transported by the P-Type ATPases, shedding light on the regulation of potassium ion concentrations within the heart.

In August, Page presented the initial results of his AHA-funded research at the International Conference on Magnetic Resonance in Biological Systems in Göttingen, Germany.

**Yury O. Tsybin**, a postdoctoral research associate with the lab's ICR program since 2004, has accepted a tenure-track position as assistant professor of physical and bioanalytical chemistry at the Department of Chemistry and Chemical Engineering, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland, http://isic.epfl.ch/. Tsybin has spent two years at the lab, focusing on different aspects of ICR mass spectrometry, including instrument and method development, and fundamentals and applications. His work has resulted in co-authoring of six published papers, one in press, and four ready for submission. At the EPFL, Tsybin will establish a high-performance mass spectrometry laboratory, including a high magnetic field Fourier transform ion cyclotron resonance mass spectrometry program, targeted at method and technique development, as well as applications in the field of structural investigation of (bio)macromolecules and their complex mixtures.

"For me, the original goal of joining the ICR program as a postdoc was to learn the dynamic and top-level research, as well as management of the leading mass-spectrometry facility in the world, headed by Professor Alan Marshall," said Tsybin. "The opportunity of working with the wide arsenal of high-resolution mass spectrometry methods and techniques provided here is unbeatable for my research field."

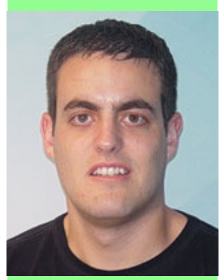
Tsybin said he looks forward to future collaboration with the ICR program and Magnet Lab, not only through mutual visits and consulting, but also by remote access to the unique mass spectrometry equipment provided by the ICR facility.

Marshall adds, "From the outset of his research career, Yury has attracted attention for his achievements, beginning with an award from the International Society for Mass Spectrometry for his Ph.D. thesis research. He has a unique knack for devising experimental conditions to expose new phenomena, and the fundamental background to develop novel models to explain his results."

Frederik Fabris

Sonia Francoual

Geoffrey Klein

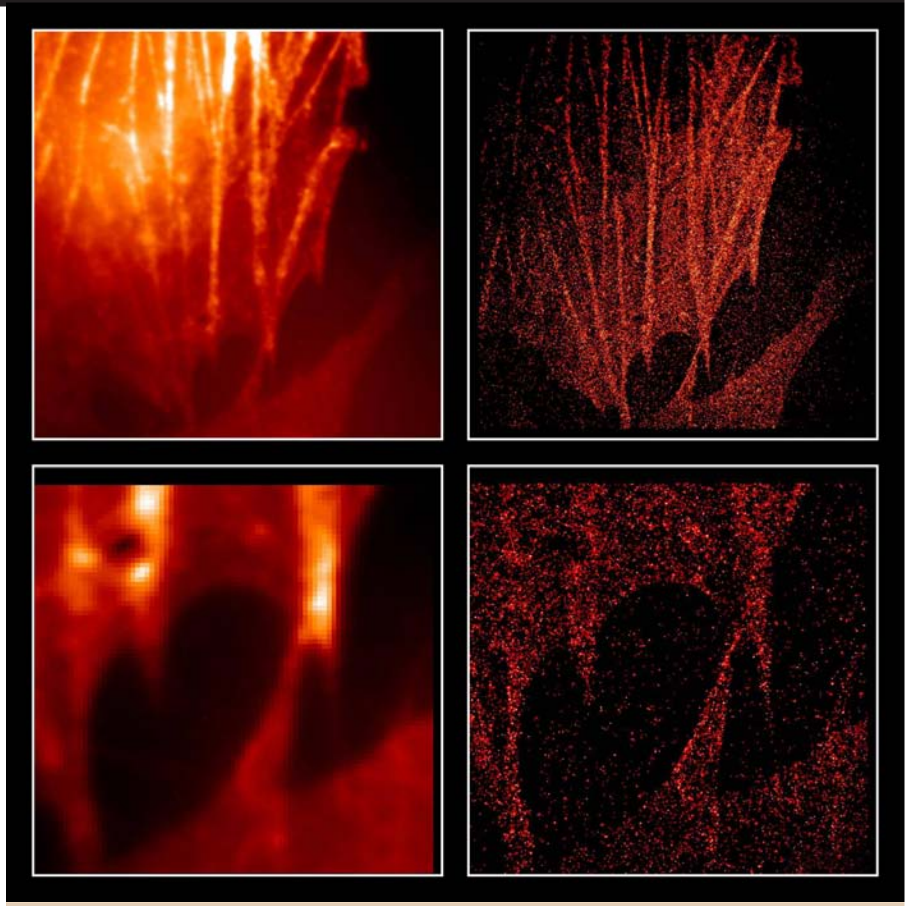


Rick Page

Yury Tsybin

# New light microscope may help unlock some of cells' secrets

A microscopy technique pioneered with the help of the Magnet Lab has led to the development of a new light microscope capable of looking at proteins on a molecular level.



The images on the left show a cell as seen with a traditional wide-field microscope; the image on the right shows the same cell imaged using the PALM technique.

The new light microscope is so powerful it allows scientists to peer deep inside cells to see the fundamental organization of the key structures within. Developed by researchers at Howard Hughes Medical Institute's Janelia Farm Research Campus in Virginia and the National Institutes of Health, in collaboration with Michael Davidson and Scott Olenych, the microscope is a boon to basic cell biology.

"As the technology advances, it may prove to be a key factor in unlocking the molecular-level secrets of intracellular dynamics," said Davidson, who directs the Magnet Lab's optical microscopy group.

The microscope and technology appeared online in the Aug. 10 issue of *Science Express.*

The idea for the light microscope and the related new method, called photoactivated localization microscopy, or PALM, was conceived by physicists Eric Betzig and Harald Hess at Janelia Farm, but they struggled with how to realize heir vision. It was biological tools being studied in Davidson's lab that ultimately inspired the two physicists' plan to build a better microscope.

"In the world of biology there is a new generation of fluorescent proteins that you can switch on at will with a little bit of violet light," Hess said. He and Betzig learned of these molecules, pioneered by Jennifer Lippincott-Schwartz and George Patterson at NIH, during conversations with Davidson.

Davidson suggested that these "optical highlighters" would be the best candidates for Betzig and Hess's experiments. Davidson's group then genetically engineered the highlighters and fused them to natural proteins in his lab. This technique allowed the researchers to attach a label to each copy of a protein they wished to study.

Here's how the PALM technique works: The researchers label the molecules they want to study with a photoactivatable probe, and then expose those molecules to a small amount of violet light. The light activates fluorescence in a small percentage of molecules, and the microscope captures an image of those that are turned on until they bleach. The process is repeated approximately 10,000 times, with each repetition capturing the position of a different subset of molecules.

When a final image is created, it has a resolution previously only achievable with an electron microscope. However, the contrast in electron microscopy is more indiscriminate, whereas PALM can limit contrast to specific proteins of interest.

Lippincott-Schwartz said the use of PALM in conjunction electron microscopy is particularly powerful.

"A great feature of PALM is that is can readily be used with electron microscopy, which produces a detailed image of very small structures – but not proteins – in cells," she said. "By correlating a PALM image showing protein distribution with an electron microscope image showing cell structure of the same sample, it becomes possible to understand how molecules are individually distributed in a cellular structure at the molecular scale."

The work was supported by the Howard Hughes Medical Institute and the National Institutes of Health.

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