NATIONAL HIGH MAGNETIC FIELD LABORATORY

REPORTS

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NHMFL REPORTS

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FROM THE DIRECTOR'S DESK

Our cover story features the commissioning of the 900 MHz, ultra-wide bore NMR magnet in late July, at which we hosted folks from the National Science Foundation, the National Institutes of Health, and dozens of representatives from industry and academia. Media interest was wonderful, including over 100 newspaper articles, a spot on National Public Radio and, of particular personal interest, a mention on the "David Letterman Show". This long-awaited commissioning highlighted three important messages: the increasing breadth of scientific research reliant upon the highest available magnetic fields; our demonstrated expertise for design and construction of unusually demanding superconducting magnets; and, perhaps most importantly, the value of having all of this under the same roof.

The completion of the "900 ultra-wide bore" was a tremendous R&D achievement made possible by sustained support from both the National Science Foundation and Florida State University. This new 21.1 T magnet provides the magnetic field intensity, homogeneity and stability of the world's best NMR magnets, but the MagLab's engineers and technicians have achieved this performance in a 105 mm diameter warm bore, which provides an order of magnitude more experimental volume than typical NMR magnets. See page 8 for more information on the 900 MHz magnet and the commissioning ceremonies.

Immediately after the champagne bottles ran dry, a spirited workshop discussed the many scientific opportunities enabled by the 900 ultra-wide bore, including new collaborative opportunities between MagLab scientists from our branches at the University of Florida (UF) and Florida State University (FSU). Art Edison, director of AMRIS, the MagLab's MRI program at UF, and Tim Cross, director of CIMAR, the MagLab's NMR Spectroscopy and Imaging Program at FSU, both are excited by the prospects.

This issue features our usual reports on new science, magnet development, and education outreach. It also includes news of three successful proposals of great importance to the MagLab:

- The NSF has awarded funding for the conceptual design of a Free Electron Laser that will integrate with existing DC magnets and provide unprecedented tuneability, brightness, and temporal resolution in the low terahertz through near infrared region of the spectrum. With Hans van Tol (MagLab/FSU) as PI, this collaboration includes MagLab/FSU (Louis-Claude Brunel), MagLab/LANL (John Singleton), Jefferson Labs (George Neil), UCSB (Mark Sherwin) and many others.
- The DOE (NNSA) has awarded a grant for research collaborations among the MagLab and Historically Black Colleges and Universities (HBCUs). With Stan Tozer (MagLab/FSU) as the MagLab lead, this is a collaboration among the MagLab/FSU (Tim Murphy, Eric Palm), Prairie View A&M (Kevin Storr, the award PI, and Orion Ciftja), and North Carolina A&T (Abebe Kebede). Six new summer REU students and five HBCU undergraduate students will visit the MagLab/FSU to study actinides and related materials under pressure, temperature, and magnetic field, research of interest to the NNSA and DOE.
- The NSF recently awarded funding to Peter Kalu (FAMU/FSU Professor of Engineering) and Ke Han (MagLab/FSU) for development of a Field-Emission SEM to study metallic micro- and nano-composites of interest for magnet applications requiring extremely high-strengths. The multi-year collaboration of Prof. Kalu and the MagLab metallurgists and electron microscopists has very successfully trained young researchers who will increase the diversity in our nation's engineering and scientific workforce.

These awards illustrate the laboratory's strong commitment to joint proposals and collaborations and to providing real-world research experiences for graduate and undergraduate students. For further information on these awards, see page 22.

The laboratory is very pleased to welcome Susan Ray as the MagLab's new Director of Public Affairs. Ms. Ray brings extensive communications experience from the private sector to this key MagLab position (see page 25), and we are confident she will help us promote the laboratory among local, regional, national, and international audiences.

As this issue goes to press, the recovery from Hurricanes Katrina and Rita is underway. Several displaced scientists will be hosted at the MagLab/FSU. Also, to address energy shortages, the MagLab has been asked to shift its powered magnet operations away from the afternoon period of peak loads. With the dedication of the MagLab's Instrumentation and Operations Group, our powered magnets are now operating from 5:00 a.m. to 12:00 noon and from 9:00 p.m. to 4:00 a.m. We appreciate the understanding and support of our users and staff during this difficult period.

On the significance of the 900…

"Pharmaceuticals or drugs bind to biological molecules and interfere or enhance their biological function. Amantadine, for example, binds to a particular protein (the M2 protein) in the influenza viral coat, preventing it from functioning and terminating the viral infection. Today, we are using the new magnet with collaborators from Northwestern University and Brigham Young University to define the detailed shape and chemical properties of the M2 protein so that a more specific drug for this protein can be designed.

"In similar fashion, the electrical and physical properties of materials can be characterized, leading to the development of novel materials."

Tim Cross

FROM THE CHIEF SCIENTIST'S DESK

A long-lasting collaboration between John Mydosh from the Max-Planck Institute for Chemical Physics of Solids in Dresden and researchers at the NHMFL Pulsed Field Facility at Los Alamos National Laboratory has produced more exciting results recently with the discovery of a single magnetic-field induced phase in $URu_{1.92}Rh_{0.08}Si_2$ in close proximity to a metamagnetic quantum critical point. $CeRu_2Si_2$ provides good control sample for seeing what happens without super exchange interactions, enabling the understanding of the specific heat at high magnetic fields.

5*f* Electrons Avoid Quantum Critical Point Singularities in $U(Ru,Rh)_2Si_2$

A.V. Silhanek, NHMFL/LANL
N. Harrison, NHMFL/LANL
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A quantum-critical point is a singular feature in the phase diagram of matter at the absolute zero of temperature. At this point, quantum fluctuations that result from the Heisenberg uncertainty principle acquire a divergent characteristic length. Quantum fluctuations originating from this singularity influence the physical properties of matter over an expanding region of phase space (pressure, magnetic field, and chemical doping) as the temperature increases. Several unexpected ordered states in strongly correlated matter, including unconventional superconductivity in *f*-electron intermetallics and *d*-electron oxides, occur in the vicinity of a magnetic quantum-critical point. Consequently, theoretical models have focused on the role of symmetry-breaking quantum-critical points in their formation.

In this work, the first direct thermodynamic evidence for the avoidance of a nonsymmetry-breaking quantum-critical point by the creation of a new low temperature ordered state is presented. This evidence is obtained by measuring the specific heat vs. temperature at constant magnetic fields in the 45 T Hybrid magnet

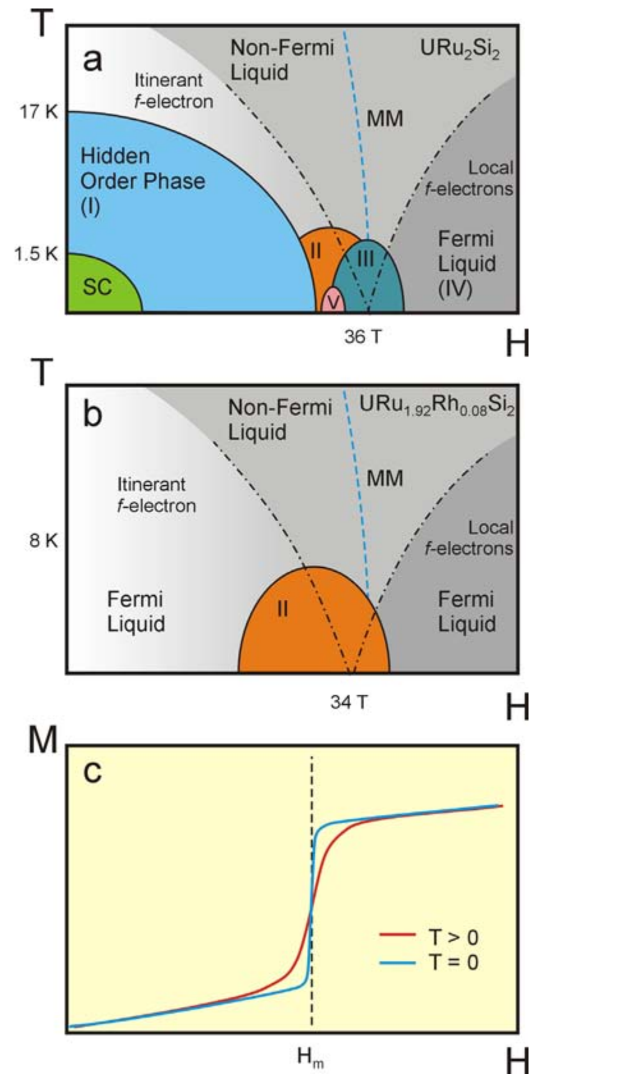


Figure 1. (a) The (H,T) phase diagram for URu_2Si_2 shows several field-induced phases in the proximity to a metamagnetic (MM) quantum critical point. (b) The *(H,T)* phase diagram is highly simplified for $URu_{1.92}Rh_{0.08}Si_2$. Only phase II and the metamagnetic transition (MM) survive the doping effects. (c) Schematic behavior for the magnetization vs. field curves in a metamagnetic system when the temperature is reduced to zero.

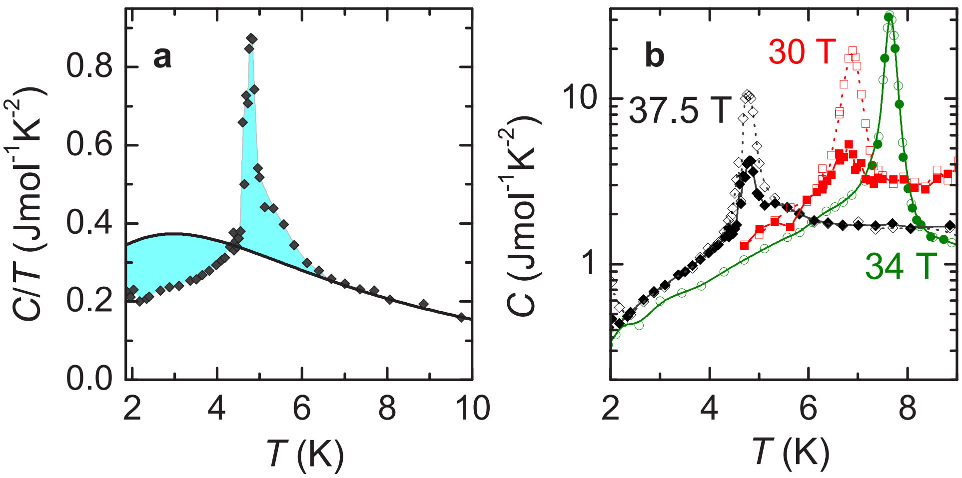


Figure 2. (a) Specific heat divided by the temperature C/T vs. temperature measured at H = 37.5 T. It is apparent that the 5*f*-electron entropy is redistributed upon entering the ordered phase below T = 5K. (b) Specific heat anomaly measured at several different magnetic fields show strong irreversibility. Open symbols where measured during warm up, solid symbols during cool down.[3]

in Tallahassee, FL. Quantum criticality is caused by metamagnetism induced by strong magnetic fields in 4% Rh-doped URu_2Si_2, where Rh substitutes Ru so as to yield $URu_{1.92}Rh_{0.08}Si_2$. The 4%-doped sample has an advantage over pure URu_2Si_2 in that the hidden order phase is suppressed with a minimal amount of doping, leading to a much simpler phase diagram with only a single field-induced phase (phase II), while the metamagnetism remains mostly unchanged as schematically displayed in Figs. 1(a) and 1(b).[1]

Our specific heat measurements reveal the presence of narrow 5*f* quasiparticles bands at high magnetic fields, whose entropy then drops abruptly on entry to this ordered phase at a distinct first-order phase transition. Irreversibility of the transition yields that it is of first order, suggestive of a strong coupling of the ordering 5*f*-electron degrees of freedom to the lattice.

URu_2Si_2 and its Rh-doped alloys belong to a class of strongly-correlated metals that includes $CeRu_2Si_2$, UPt_3, and $Sr_3Ru_2O_7$, in which the *d* or *f* electrons are itinerant (i.e., they contribute to the metallic properties of the material) but are on the threshold of becoming localized and giving rise to magnetism. By coupling directly to their spin degrees of freedom, strong magnetic fields can coax the *d*- or *f*- electrons into a polarized state. "Metamagnetism" results when this transformation occurs abruptly at a critical magnetic field H_m, as depicted in Fig. 1(c). Should H_m evolve from a crossover at finite temperatures into a phase transition very close to absolute zero, it then develops all of the characteristics of an isolated nonsymmetry-breaking quantum-critical point.

Stoichiometric URu_2Si_2, $CeRu_2Si_2$, and $Sr_3Ru_2O_7$ are sufficiently close to quantum criticality for their physical properties to be strongly influenced by fluctuations at temperatures $T \approx 1$ K. Being composed of 5*f*-electrons that have properties intermediate between those of the *d* electrons in transition metal oxides and 4*f*-electrons in rare earth intermetallics, actinide intermetallics such as $U(Ru,Rh)_2Si_2$ occupy a unique vantage point for understanding the dynamics of quantum criticality in the formation of new states.

While not as spatially extended as *d*-orbitals, the 5*f*-orbitals of U exhibit a sizeable degree of superexchange between neighboring U sites, greatly increasing the likelihood of an ordered state over its 4*f* analogue, Ce. As with 4*f*-electrons, however, the on-site Coulomb repulsion between 5*f*-electrons is sufficiently strong to facilitate the formation of renormalized (narrow) quasiparticle bands upon their hybridization with regular conduction bands. This has two immediate benefits: first, the narrow 5*f* quasiparticle band can be completely polarized by magnetic fields that are available in the laboratory. H_m in $URu_{1.92}Rh_{0.08}Si_2$ occurs at H = 34.4 T, bringing it well within the limits (45 T) of the highest available static magnetic fields. Second, the Fermi temperature ($T^* < 20$ K) of these quasiparticle bands is significantly lower than the characteristic Debye temperature ($T_\theta \gg 30$ K) of the phonons (or lattice vibrations), making the magnetic field-dependent degrees of freedom of these polarized bands readily accessible to fundamental thermodynamic probes such as the specific heat.

Such specific heat vs. temperature was measured in $URu_{1.92}Rh_{0.08}Si_2$ (Ref. 2) for magnetic fields large

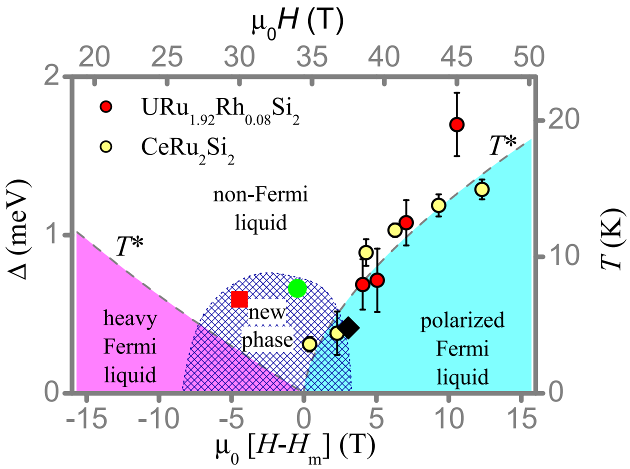


Figure 3. Fitted values of the hybridized bandwidth Δ for both $URu_{1.92}Rh_{0.08}Si_2$ and $CeRu_2Si_2$, as indicated, plotted vs. H - H_m (and also H in the former case). The dashed gray lines denote the regions of Fermi liquid and non-Fermi liquid recently identified from a crossover T^* in the electrical resistivity. The vertical axes Δ and T are scaled only by the Boltzmann constant k_B, revealing that $k_B T^* \approx \Delta$. A new phase (hashed region from Kim *et al.*[1] is observed only in $URu_{1.92}Rh_{0.08}Si_2$ (not $CeRu_2Si_2$) as a means to avoid the putative quantum-critical point. The maxima in Cp vs. T associated with this phase boundary are represented by colored symbols as presented in Fig. 2.

enough to suppress completely phase II up to H = 45 T. In this region, the specific heat is calculated assuming the existence of a doublet *f*-electron level in the close proximity to the Fermi energy, that is split by Zeeman effect with increasing magnetic field.[2] Fig. 3 shows that the fitted bandwidth Δ for both $URu_{1.92}Rh_{0.08}Si_2$ and $CeRu_2Si_2$ plotted vs. H-H_m, is the same for both systems, within experimental uncertainty. For both systems the *f*-electron quasiparticle bands become progressively narrower as the spin fluctuations intensify near H_m. The dashed line in Fig. 3 shows an independent estimate of the Fermi temperature T^* of the quasiparticle bands obtained from magnetotransport measurements on $URu_{1.92}Rh_{0.08}Si_2$ (Ref. 1). Its consistency with Δ provides the first confirmation of a direct correlation between features observed in the electrical resistivity and the hybridized bandwidth.

1 Kim, K.H., *et al*., *Phys. Rev. Lett*., **93**, 206402 (2004).
2 Silhanek, A.V., *et al*., *Phys. Rev. Lett*., **95,** 026403 (2005).
3 Silhanek, A.V., *et al*., condmat\
4 van der Meulen, H.P., *et al.*, *Phys. Rev. B*, **44**, 814 (1991).

Attention Users
DC FIELD FACILITY

Bruce Brandt, Director, DC Field Facility

I have a few brief notes about developments in the DC Facility to share with you; brief, but important.

The major parts of the facility improvements that are being funded by the State of Florida's $7.5 million appropriation[1] are in place or on order. Construction of the three million gallon chilled water storage tank is proceeding rapidly. The additional pumps needed to allow us to run magnets for up to 15 hours straight are on order. Our days of tensely watching the chilled water supply and curtailing operations when it ran out will soon be over. The new transformers that will allow full power operation and increase the amount of available power have been designed and are being built. The first ones will be delivered in December. The new rectifier controllers, which we expect/hope will improve the stability and reliability of our power supplies are also being readied for delivery in late December or January. That leaves only some smaller parts of the upgraded power supplies still to be ordered.

We expect to have everything working together by the summer of 2006. That's the very good news. The fly in the ointment is some disruption of operations starting in January as we install and test the controllers and then some of the other equipment. The work will occasionally limit magnet operations to 20 MW, which means only one magnet at a time and no 45 T Hybrid. The duration of each limitation will depend on how much trouble we have installing and tuning the new controllers. It might be a week here and there, or several weeks in a block. (Please note that the 45 T Hybrid is routinely shut down for preventive maintenance from early March through the end of May.) We are very excited about this improvement of our basic infrastructure and believe that the possible disruptions of operations will be much smaller than the benefits.

Much less dramatic and expensive, but good news anyway, is the availability of our new helium three refrigerator for samples in vacuum in 32 mm bore magnets. Tim Murphy reported the following results of tests in field:

- Base Temperature = 270 mK (zero field), ~275 mK (fixed field)
- Maximum Sample Temperature = 70 K (nominal)
- Time to cool = 3.5 hours (300 K to 0.27 K). Time includes inserting cryostat into dewar, pumping the inner vacuum chamber's exchange gas, condensing the helium three (40 minutes) and cooling the sample to 270 mK.
- ^{3}He Hold Time = 30 hours at zero field. This is a nominal value with no added heat load. Hold time during high field experiments with current in the sample will be less.
- Dewar Hold Time = 30 hours for liquid helium four and 48 hours for the liquid nitrogen.
- Ramping the magnet at 1.2 T per minute raised the sample temperature 37 mK. The temperature recovered to the base temperature four minutes after the field stopped changing.

This system was designed and built with heat capacity and other thermal measurements in mind, but is available now for any measurements that require temperatures lower than the 400 to 500 mK that our simpler helium three refrigerators reach in 32 mm bore magnets.

The NHMFL Users' Committees will be meeting at the University of Florida in Gainesville October 28. Users should write to or talk with James Valles, Users' Committee Chair if they have any concerns about magnet or instrumentation priorities, services provided to users, and so forth. Jim may be reached at 1-401-863-3084 or *valles@physics.brown.edu*.

And finally . . . **Scott Hannahs, NHMFL Instrumentation Guru, has helped Keithley Instruments win its 19th prestigious R&D 100 Award** for special functions that are possible with the combination of their new Model 6221 Precision AC/DC Current Source and Model 2182A Nanovoltmeter. Called "the Oscars of Invention" by the *Chicago Tribune*, the R&D 100 Awards are presented by *R&D Magazine* and recognize the 100 most innovative and technologically significant products introduced into the marketplace during the past year. The editors of *R&D Magazine* and a panel of independent industry experts select the winners.

Keithley's Model 6221 Precision AC/DC Current Source can source low currents with high accuracy. Built-in control functions make it ideal for characterizing semiconductor and nanotechnology materials. The Model 6221 complements the Model 2182A Nanovoltmeter, an instrument that many NHMFL users employ to make low-level electrical measurements.

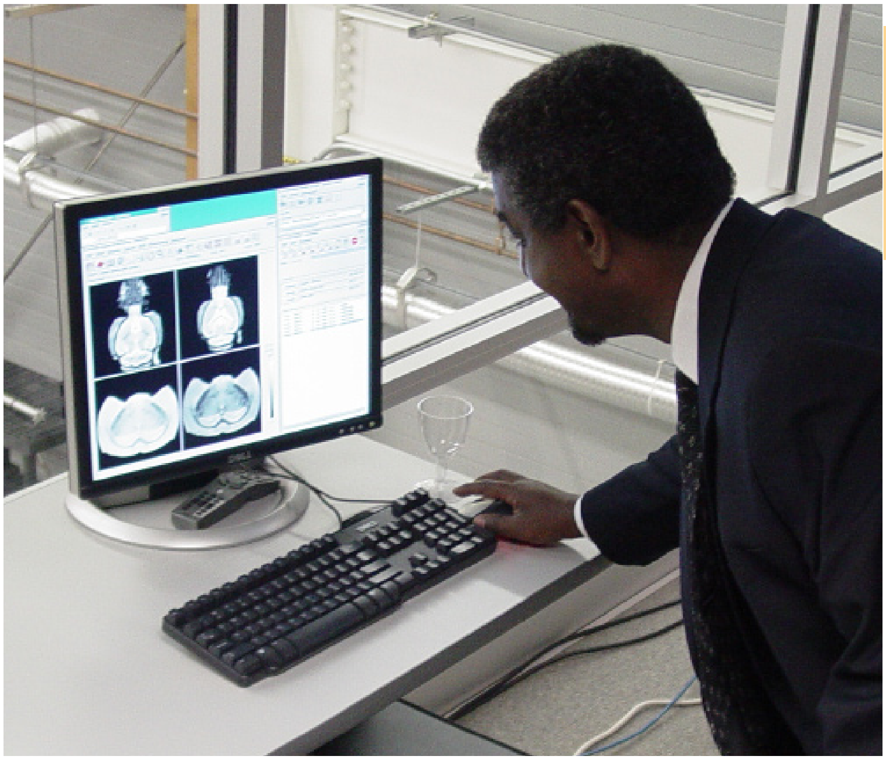
The combination Model 6221 and Model 2182A features two new functions for which Scott is responsible. The new Delta Mode of operation reverses the current and averages the absolute values of the voltages measured. This dramatically improved method eliminates excessive signal noise and drift, producing more accurate measurement results for the most demanding low-level measurement applications. This general approach has been used for years by scientists writing the numbers in notebooks and doing the averaging with a calculator. Scott Hannahs automated the process several years ago using software built into his NML Data Acquisition program to control older model Keithley current sources and nanovolt meters. He showed the technique to Keithley engineers during several of their occasional visits to the NHMFL and urged them to make it easier and more generally available. He also persuaded them to consider using the same technique with different internal calculations to measure differential conductance. Once the features had been built into the hardware, Scott tested the features ruthlessly in the challenging test bed that is the DC High Field Facility. When the process was complete, he ordered several of the 6221 sources for the users, at a price discounted more than usual.

Hannahs will be accompanying Keithley engineers to the awards banquet at Chicago's Navy Pier in October. His colleagues are hoping to see a photo of Scott in a tuxedo.

The collaboration between Keithley Instruments and the National Magnet Lab goes back to the 1960's and our predecessor lab at M.I.T. Keithley Instruments donated over a hundred thousand dollars worth of instruments and services to the NHMFL when it was just beginning, resulting in the designation of the Joseph F. Keithley magnet cell in Tallahassee.

[1] *Editor's Note:* The State's special appropriation in 2004 was for $10 million; $2.5 million will be used for enhancements to NHMFL facilities at UF.

900 MHz Magnet: Commissioned and Open to Users!



DR. TESSEMA OF THE NATIONAL SCIENCE FOUNDATION STARTS THE IMAGING OF A RAT BRAIN DURING 900 MHZ COMMISSIONING CEREMONIES.

The Magnet Lab marked a major scientific leap forward with the commissioning of world-record 900 megahertz (MHz) magnet on July 28, 2005. About 150 people attended special ceremonies that featured a live imaging demonstration of a mouse brain and remarks by FSU President T.K. Wetherell; UF Dean of Arts and Sciences and Magnet Lab co-PI Neil Sullivan; and NSF Program Director for National Facilities Guebre Tessema.

This spectacularly precise magnet is expected to yield important discoveries in the fields of chemical and biomedical research. An early indication of its productivity and promise came in a surprise revelation by one of the distinguished guests in attendance: Stanley J. Opella of the University of California, San Diego. Opella serves as editor of the prestigious *Journal of Magnetic Resonance* and announced that the new magnet would be the cover story of the journal's November 2005 issue.

The new superconducting magnet, which stands 16 feet tall and weighs more than 15 tons, was no overnight accomplishment. A team of engineers based at the Magnet Lab worked for 13 years to develop, design, manufacture, and test it. Several outside companies, including Intermagnetics General Corporation, collaborated with the lab during this process. At full strength, the magnet reaches 21 T, or about 420,000 times the Earth's magnetic field, in a 105 mm bore. The fields vary by less than 0.0000002 T over a volume roughly equal to the size of a small orange—an accomplishment unrivaled anywhere else in the world.

In his opening remarks, NHMFL Director Greg Boebinger reminded guests that "the commissioning of the Magnet Lab's new 900 megahertz NMR magnet marks the successful completion of the third of the "Big Three" magnet projects on which the lab was founded by the National Science Foundation in 1990. Whereas our other big magnet projects—the 45 T Hybrid and the 60 T Long-Pulse—specialized in making the most powerful magnetic fields, this magnet specializes in precision.

"In addition to their still-unequaled achievements in very powerful magnets over the past decade, this outstanding engineering project demonstrates our Magnet Science and Technology Team to be uniquely talented in bringing precision superconducting magnets to scientific research," Boebinger said. "The

Top left) Large audience comprising NHMFL faculty and staff, guests, and media listen to Professor Art Edison, director of the Advanced Magnetic Resonance Imaging Facility at UF, explain science opportunities of the 900 MHz (shown on right). NHMFL Director Greg Boebinger remarks on the completion of the laboratory's "Big Three" projects: the 60 T Long-Pulse (completed in 1997), the 45 T Hybrid (completed in 1999), and now the 900 MHz system.

incredibly precise magnetic fields of the 900 MHz magnet immediately position our chemistry and biology research programs at the forefront of magnetic resonance research—research that will help us understand the workings of biological molecules, as well as the workings of the cell and the brain. Its large volume also enables us to probe the unusual properties of materials under extreme conditions of heat and pressure similar to those found deep in the Earth."

News of the magnet made headlines across the nation and around the world. Over 100 media outlets carried the story, including National Public Radio, the *Washington Post*, the *Washington Times*, the *San Francisco Chronicle*, *USA Today*, the *LA Times*, *Tech News World*, the *Miami Herald*, the *Gainesville Sun*, and the *Tallahassee Democrat*.

For information about the 900 MHz and to request magnet time, refer to the NMR Program Web site (*http://nmr.magnet.fsu.edu/*) or contact Bill Brey (*wbrey@magnet.fsu.edu*) or Riqiang Fu (*rfu@magnet.fsu.edu*).

Editor's note: Barry Ray, FSU Media Relations, contributed to this article.

This newsletter has frequently reported the progress of the 900 MHz. For more information on its R&D and science opportunities, see:

900 MHz Reaches Full Field . . .Sets New Dimensions!, July 2004
http://www.magnet.fsu.edu/spotlights/900MHzff/

Ultra-Wide Bore 900 MHz Bucket Test, Installation, and Commissioning, August 2003
http://www.magnet.fsu.edu/spotlights/900MHz-3/

Relocation of 900 MHz Magnet, April 2003
http://www.magnet.fsu.edu/spotlights/900MHzmove/

Scientific Vision for 900 MHz Magnet, October 2002
http://www.magnet.fsu.edu/spotlights/900Mhz-2/

Successes and Challenges of Initial Testing of the Wide Bore 900 MHz Magnet, May 2002
http://www.magnet.fsu.edu/spotlights/900MHzwidebore/

Wide Bore 900 MHz Project Bucket Test, August 2001
http://www.magnet.fsu.edu/spotlights/900MHz/

Magnetic Resonance Microscopy of the Adult C57BL/6J Mouse Brain: The Creation of a Three-Dimensional Digital Atlas Database

S.C. Grant, University of Florida, Neuroscience
Y. Ma, Mount Sinai School of Medicine, Psychiatry
P.R. Hof, Mount Sinai School of Medicine, Neuroscience and Advanced Imaging Program
S.J. Blackband, UF, Neuroscience and NHMFL
H. Benveniste, Brookhaven National Laboratory, Medical Department and State University of New York at Stony Brook, Anesthesiology

To take advantage of information emerging from genome sequencing efforts, it is necessary to systematically collect normative phenotypic information at all biological levels, including the establishment of databases supplying baseline phenotypic data from commonly used inbred mice. The integration of visual and quantitative information gathered from 3D neuroanatomical data requires a comprehensive atlas database for data storage, data management, and retrieval. It has long been recognized that Magnetic Resonance Microscopy (MRM) has advantages in creating such a database compared to the invasive, conventional histological staining methodology because it is inherently non-destructive, digital, 3D, and potentially applicable *in vivo*. With the newest technology and higher magnetic field strengths, a large number of anatomical structures can be defined accurately in MRM. As part of this effort, we constructed an adult male C57BL/6J mouse brain atlas database derived directly from T2*-weighted 3D MRM images acquired on a 17.6 T magnet. With 20 segmented structures, this digital brain atlas database offers three different formats (individualized brain atlases, a minimal deformation atlas, and a probabilistic atlas), as well as associated quantitative information. This development is intended to augment the shortcomings of currently available 2D and 3D atlases and to provide new quantitative anatomical information as well as additional computational templates for integrating other information, such as function and gene expression patterns.

Ten intact, fixed mouse brains were imaged using a 3D gradient-echo pulse sequence at a 47-µm isotropic resolution in 5.5 hours. Following imaging, brain images were segmented semi-manually into 20 regions of interest (ROI) that could be identified with the least ambiguity. The regions included the neocortex, hippocampus, amygdala, olfactory bulbs, basal forebrain, septum, caudate-putamen, globus pallidus, thalamus, hypothalamus, central gray, superior colliculi, inferior colliculi, the rest of midbrain, cerebellum, brainstem, corpus callosum/external capsule, internal capsule, anterior commissure, fimbria, and ventricles. From the finalized segmentations of the 10 C57BL/6J brain MRM images, we constructed an atlas database that included the following: 10 individualized single specimen atlases, probabilistic atlases of the whole brain and individual structures, and a local deformation map.

Individualized atlases and quantitative structural information

Because all brains were segmented accurately using a deformable atlas-based automatic approach, each segmented dataset serves as an individualized atlas with 20 outlined brain structures. Averaged structural volumes, surface areas, and T2*-weighted normalized MRM intensity of each of the 20 segmented regions with their standard deviations were calculated for all 10 mouse brains. The standard deviations of the segmented structure volumes varied from 0.1 mm^3 (central gray, globus pallidus, and internal capsule) to 6.0 mm^3 (neocortex), which can be considered small. The standard deviation of corresponding surface areas varied from 0.6 mm^2 (central gray) to 14.4 mm^2 (corpus callosum/external capsule).

Probabilistic atlas

A probabilistic atlas represents the anatomic variability between individual brains using a statistical confidence limit rather than an absolute representation of neuroanatomy. We constructed a 3D volumetric probabilistic atlas for the 20 segmented structures of the

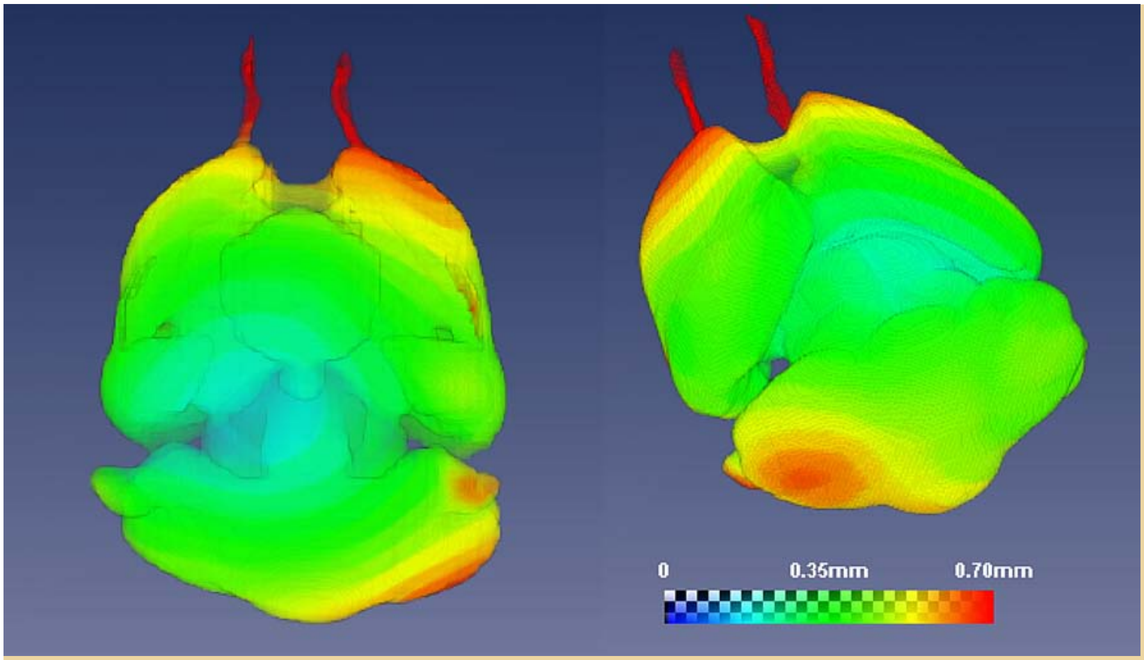


Figure 1. Two volume renderings of the 3D average deformation map of 13 segmented regions of interest structures registered to the reference brain. The brighter the color, the bigger the average deformation the group underwent to register with the reference brain, which is indicative of a larger group variation.

10 C57BL/6J brains as follows. The 10 individual atlases were superimposed and the probability of a certain structure occupying a particular voxel in the reference brain space was calculated. The atlas then was color-coded, and the variant structure occupancy at different locations was visualized in 3D. Using different confidence levels, thresholding was applied to the probabilistic atlas to produce individual atlases with clear-cut structural boundaries. Confidence levels of the structure boundaries are pre-determined by using empirical thresholds. When thresholded at different values, the probabilistic atlas can provide clearly defined structure boundaries with varied degrees of accuracy. Close to full structure delineation is given at a threshold of 50%.

Deformation map

The deformation map is obtained from the deformation vector fields calculated when two images are registered. It presents the displacement that each voxel in one brain has to undergo to match its corresponding location in another brain. Because the target brains were initially registered with the reference brain through affine transformation, the deformation represents higher order geometrical variations other than global differences such as brain location or brain sizes. A 3D volume-rendered, color-coded display of the local deformation map is demonstrated in Fig. 1 with brighter colors representing the larger voxel displacement. Both the cerebellum and anterior commissure contain areas that display larger displacements compared with other structures. Note that the thalamus, located in the center of the brain, displays the least amount of displacement.

Conclusion

As expected, among the 10 genetically identical C57BL6/J mouse brains, we found small structural volume and surface area variability. For identical structures, our data are fully comparable to those obtained from nine male 129S1/SvimJ mouse using MRM technology.[3] Although MRM offers advantages for creating 3D rodent brain atlases, far fewer brain regions can be labeled compared to histological atlases, for which labeling is accomplished by using different chemical stains. In a similar fashion, the MRM technique also has several contrast mechanisms, such as T1-, T2-, MT- and diffusion-weighting as well as exogenous MR-"active agents,"[2] that need to be explored for future anatomical labeling. Another approach is to use a multi-modality imaging approach that combines 3D representations of MR and histological acquisitions. In this vein, current efforts are underway to utilize the 21.1 T magnet (900 MHz) at the NHMFL to evaluate potential gains in signal and contrast enhancements of the C57BL/J6 mouse brain that may be afforded by the increased field strength.

Acknowledgements

The authors acknowledge support from the NIH (R01 EB 00233-04 and P41 RR16105) and the NHMFL. MRI data were obtained at the Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) facility in the McKnight Brain Institute of the University of Florida.

1 Ma, Y., *et al*., *Neuroscience,* **135**, 4 (2006).
2 Johnson, G.A., *et al., Radiology,* **222**, 789-793 (2002).
3 Kovacevic, N., *et al*., *Cerebral Cortex*, **15**, 639-645 (2005).

News From NHMFL National FT-ICR Mass Spectrometry Facility

A.G. Marshall, ICR Program Director (FSU)
J.R. Eyler, ICR Program Co-PI (UF)
C.L. Hendrickson, NHMFL
M.R. Emmett, NHMFL
R.P. Rodgers, NHMFL
G.T. Blakney, NHMFL
C.L. Nilsson, NHMFL

Need for High Field. More than for any other form of magnetic resonance spectroscopy, Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) benefits from high magnetic field, B.[1] Fig. 1 shows how seven independent figures of merit increase as B or B^2. NHMFL's first FT-ICR instrument featured a 9.4 T magnet (highest field in the world in 1995), and its current 14.5 T magnet is the highest field in the world today (see Fig. 2). With support from NSF, the Korea Basic Science Institute (KBSI), and Battelle Pacific Northwest National Laboratory, NHMFL's Magnet Science and Technology group has just completed a conceptual design for the superconducting solenoid and cryostat for a 21 T horizontal 110-mm bore diameter, actively shielded ICR magnet. Funding to complete construction of three such magnets will be sought later this year.

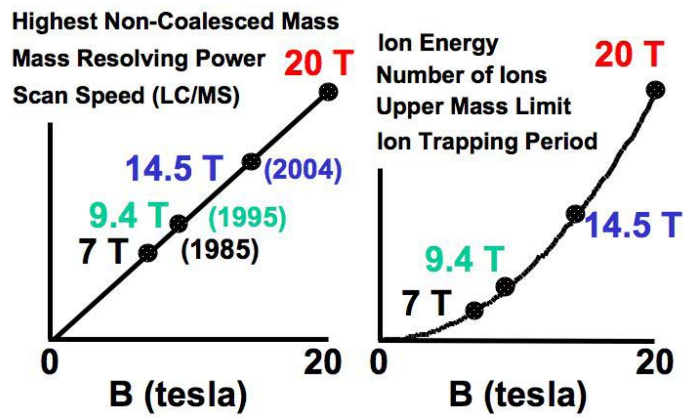


Figure 1. Seven independent figures of merit increase as B or B^2.

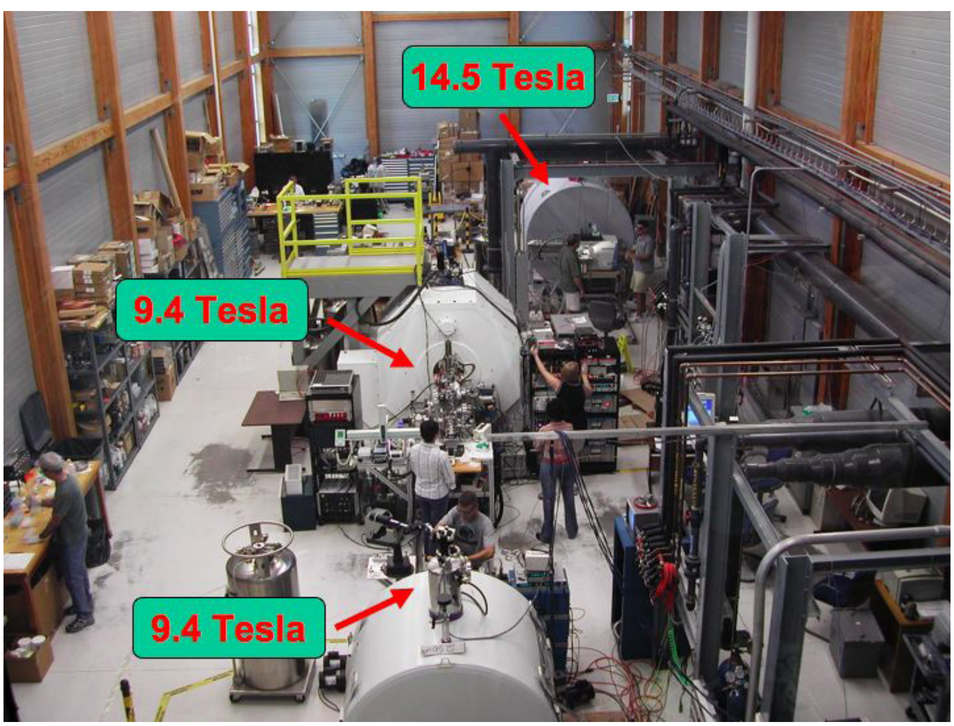


Figure 2. FT-ICR lab at the NHMFL with the 14.5 T FT-ICR magnet (the highest field in the world).

Technical Innovations. The ICR Facility's first magnet was the first shielded ICR magnet (all commercial FT-ICR superconducting magnets are now shielded). The Facility introduced external ion accumulation, a technique that made it possible to couple inherently continuous ion sources (e.g., electrospray ionization, atmospheric pressure photoionization) to inherently pulsed ICR detection, and making possible the current generation of commercial FT-ICR instruments. The Facility builds its own data acquisition systems, and has exported more than a dozen to other laboratories around the world. These and other technical innovations have enabled the ICR Facility to establish (and extend) several world records for mass resolving power and sub-ppm mass accuracy throughout a wide-range mass spectrum of organic mixtures (see below). In fact, several new instrumental techniques and modules initiated (red) or developed (black) here have subsequently been incorporated into various commercial instruments (see Fig. 3.)[2] Mass spectrometry is the fastest-growing segment of the spectroscopy market, and FT-ICR MS is growing twice as fast as mass spectrometry as a whole (~$80 M/year for a total worldwide installed base of more than 620 instruments).

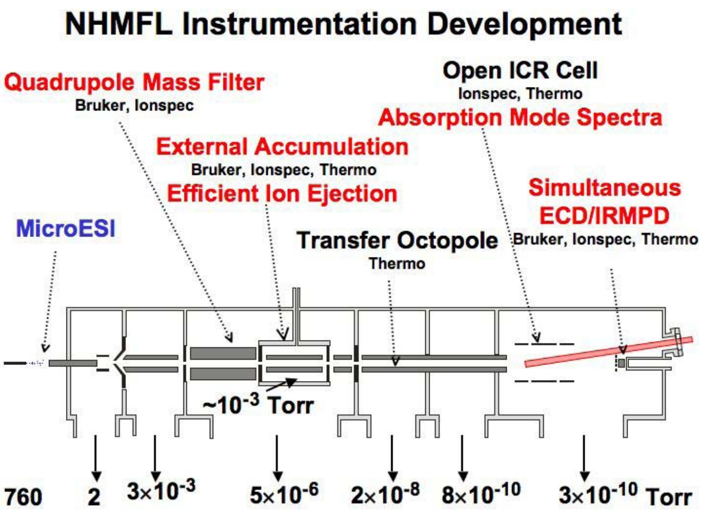


Figure 3. Several new instrumental techniques and modules initiated (red) or developed (black) have subsequently been incorporated into various commercial instruments.

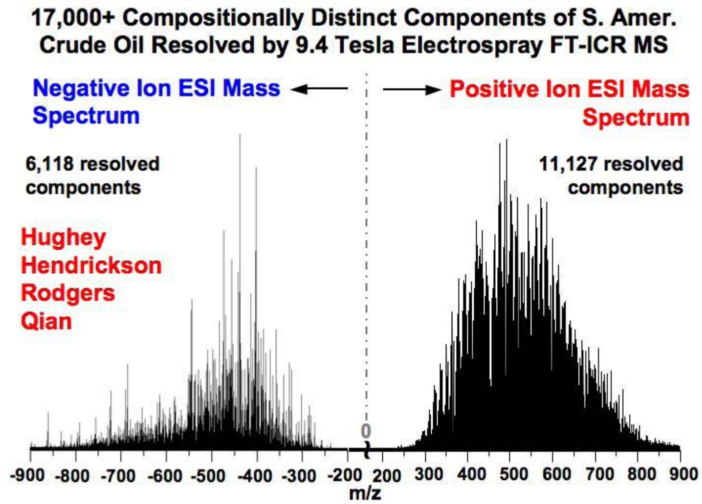


Figure 4. Detailed petroleum crude oil chemical composition.

Analytical, Chemical, and Biological Applications. Various FT-ICR MS applications have previously been chronicled in the *NHMFL Annual Reports*. For example, the ultrahigh resolving power and mass accuracy of FT-ICR MS have spawned the new field of "petroleomics."[3] It is becoming possible to correlate (and ultimately predict) the properties and behavior of petroleum crude oil and its products with their detailed chemical composition (see Fig. 4) revealed by FT-ICR MS.

Another important application area is the identification of posttranslational (i.e., beyond DNA) modifications of proteins. Fig. 5 shows how electron capture dissociation MS/MS can uniquely identify the site of phosphorylation in a proteolytic fragment of a phosphoprotein (the black fragments do not contain phosphate and the red ones do—either list suffices to find the phosphorylation site).[4]

Finally, in an international collaboration based on an FT-ICR mass spectrometer built by the Eyler group at the University of Florida and installed at a free electron laser facility in The Netherlands, the first mid-infrared (i.e., the "chemical-bond range") spectrum of a gas-phase protein has been generated (see Fig. 6).[5] The amide I and amide II vibrational band positions suggest that the protein is predominantly an α-helix in the gas phase, as in solution,

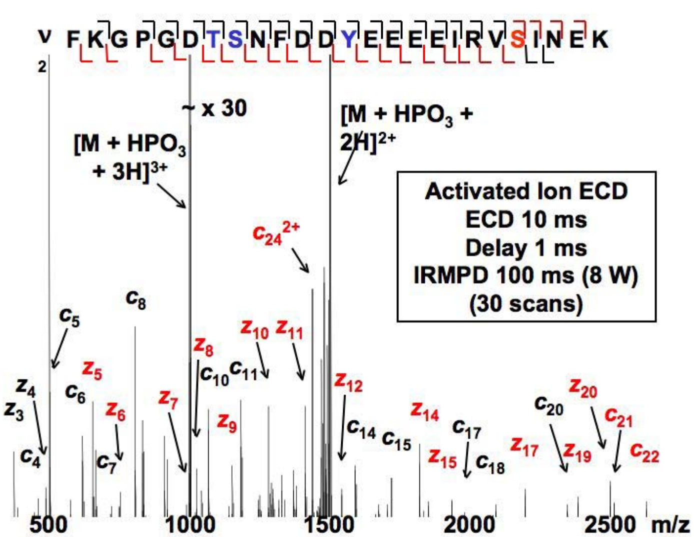


Figure 5. Electron capture dissociation MS/MS.

even though the gas-phase protein is completely unsolvated. An unexpected and not-yet-identified band appears in the gas-phase IR spectra of higher charge states, suggesting that the protein's secondary structure may change at higher charge states (a result not accessible to solution-phase measurements).

Service. A primary mission of the ICR Facility is a strong in-house (FSU and UF) FT-ICR MS research program, to ensure that new techniques (whether developed locally or elsewhere) are rapidly reduced to practice and made available to a wide user base. In 2004, some 130 external users visited the ICR Facility. We have provided technical support for more than 100 proposals by external users, leading to several million dollars in federal equipment and operating grants. The Program is currently helping KBSI to modify a commercial ICR instrument for installation in a 15 T magnet in their own laboratory in 2006. In 2004, we introduced remote operation of our 9.4 T instrument—since then, it has been

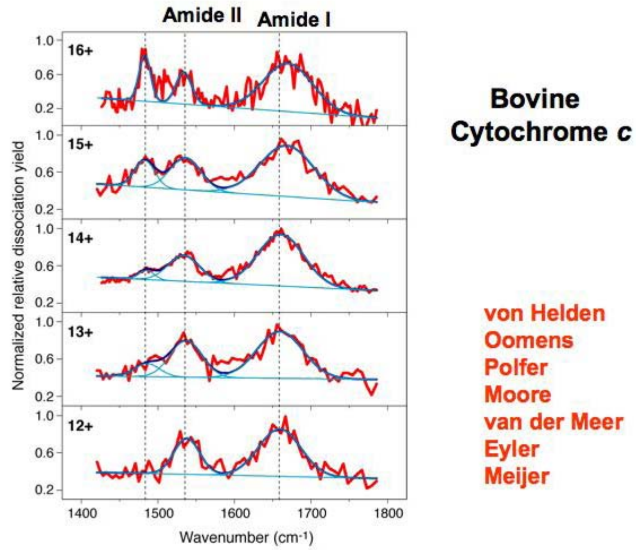


Figure 6. Mid-infrared spectrum of a gas-phase protein.

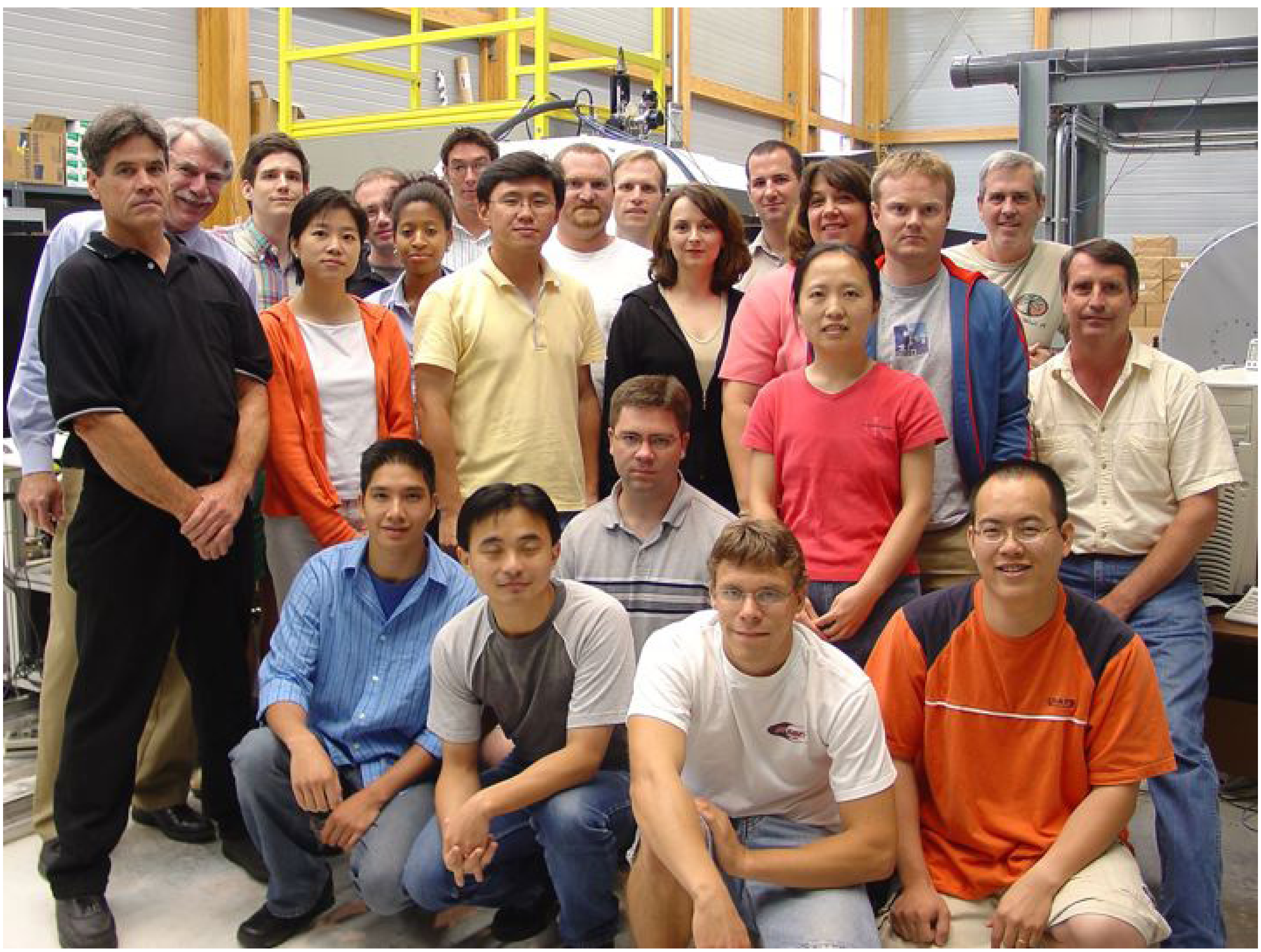


Figure 7. Members of the NHMFL ICR Program.

operated from as far away as England, and promises to broaden access to our unique instrumentation. A vital feature of the ICR User Program has been to provide free lodging for external users at a permanently rented local apartment, so that the user can stay as long as it takes to complete his/her project.

Funding. The NHMFL ICR Program is currently supported by a $1.5 million per year contribution to the NHMFL Core Grant from the NSF Division of Chemistry, approximately $0.4 million per year from the State of Florida, and several grants from oil and chemical companies. John R. Eyler at UF is a co-P.I. for the NHMFL ICR Program. Personnel in Tallahassee include Alan Marshall (director and P.I.), five Ph.D. scholar-scientists, a technician, a machinist, seven postdoctoral fellows, five graduate students, and an office assistant (see Fig. 7). In 2005, these individuals alone presented more than 100 invited and contributed talks and posters, and published more than 30 refereed journal papers. Prior publications from the Tallahassee group have averaged about 35 citations each.

Industrial Impact. Both by collaborative research and by fee-for-service (for proprietary samples), the ICR Program has enabled companies such as Wyeth-Ayerst to determine the value of FT-ICR MS for their commercial applications. Such collaborations have generated approximately $300 K in unrestricted grants from chemical and oil companies, including Dow, ExxonMobil, and Schlumberger-Doll.

External Profile and Recognitions. Since its inception in September, 1993, the ICR Program has brought major recognition to the Magnet Lab, as evidenced by 16 regional, national, and international awards; 46 web, journal, and professional magazine features (including two recent journal special issues and a cover article in the July 4, 2005 issue of *Chemical & Engineering News*).

Placement of Former Graduates. The ICR Program has an excellent record of placing its Ph.D. and postdoctoral personnel as university faculty members and as senior researchers at government and industrial laboratories. At the Tallahassee site, we are especially proud of our 3 M.S. and 13 Ph.D. FSU graduates, and 30 former postdoctoral research associates, who went on to positions at major universities (U. Alabama-Birmingham, Harvard U., U. Maine, U. Michigan, MIT, Ohio State U., Purdue U., U. Virginia, Yale U., York U. in Canada, U. Birmingham in England, and École Polytechnique in France); industry (Amgen, Bruker, Ibis Pharmaceuticals, Merck, Pfizer, Rigel, Scripps Florida, Symyx, Thermo Electron Corp., and Waters); and government laboratories (Korea Basic Science Institute, NHMFL (4), and Pacific Northwest National Laboratory).

Education and Outreach. The ICR Program initiated and continues to organize a biennial North American FT-ICR MS Conference, featuring leading-edge introduction of new techniques and applications—the 5th such Conference (in Key West, FL in April, 2005) drew 115 attendees (see separate article in this issue). The ICR Program has also logged dozens of student-semesters of undergraduate research, including several African-American students from Florida A&M University.

[1] Marshall, A.G., *et al*., *Mass Spectrom. Rev.*, **17**, 1-35 (1998).
[2] Marshall, A.G., *et al*., *Int. J. Mass Spectrom.*, **200**, 331-356 (2000).
[3] Marshall, A.G., *et al*., *Acc. Chem. Res.*, **37**, 53-59 (2004).
[4] Chalmers, M.J., *et al*., *Proteomics*, **4**, 970-981 (2004).
[5] Oomens, J., *et al*., *Phys. Chem. Chem. Phys.,* **7**, 1345-1348 (2005).

In the News . . .

The ICR Program was included in the cover story of *Chemical and Engineering News*, **83**, 27, 28-34 (2005) about analytical instrumentation and assays' roles as important tools to ensure quality and safety in the food and dairy industry. Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) is a promising technique for the direct and more complete analysis of the thousands of compounds naturally found in foods.

Collaborations Advance Magnet Technologies

T. Painter, MS&T Assistant Director

Part of the Magnet Science and Technology (MS&T) division's mission is to advance high-field magnet systems worldwide where the risk is too high for the commercial sector but where new opportunities exist for the advancement of science. One means for pursuing this mission is through collaborations with other laboratories and high-tech commercial organizations. These collaborations bring to bear the analytical, design, development, production, and test experience of the approximately 40 staff members and facilities within MS&T to support cutting-edge high-field magnet R&D. The two projects discussed here are examples of these collaborative activities.

The Advanced Photon Source (APS) is a user facility at the Argonne National Laboratories. Rather than high magnetic fields, they offer multiple beams of hard and soft X-rays extracted from a circulating beam of electrons using a variety of "insertion devices," each of which services a specific range of experiments for various scientific users. The insertion devices are typically magnetic undulators that provide specific beam frequencies and intensities, and APS is interested in increasing the combination of frequency and intensity of light to presently unavailable levels. The NHMFL, in collaboration with APS, is exploring the introduction of undulators with higher magnetic fields and shorter periods than previously available through the use of higher-performance Nb_3Sn superconductor technology. A unique cryogenic system is also being developed with the aim of reliability and redundancy so possible disturbances won't affect other systems. The first step of the APS collaboration was a feasibility study to determine a systematic approach to achieving

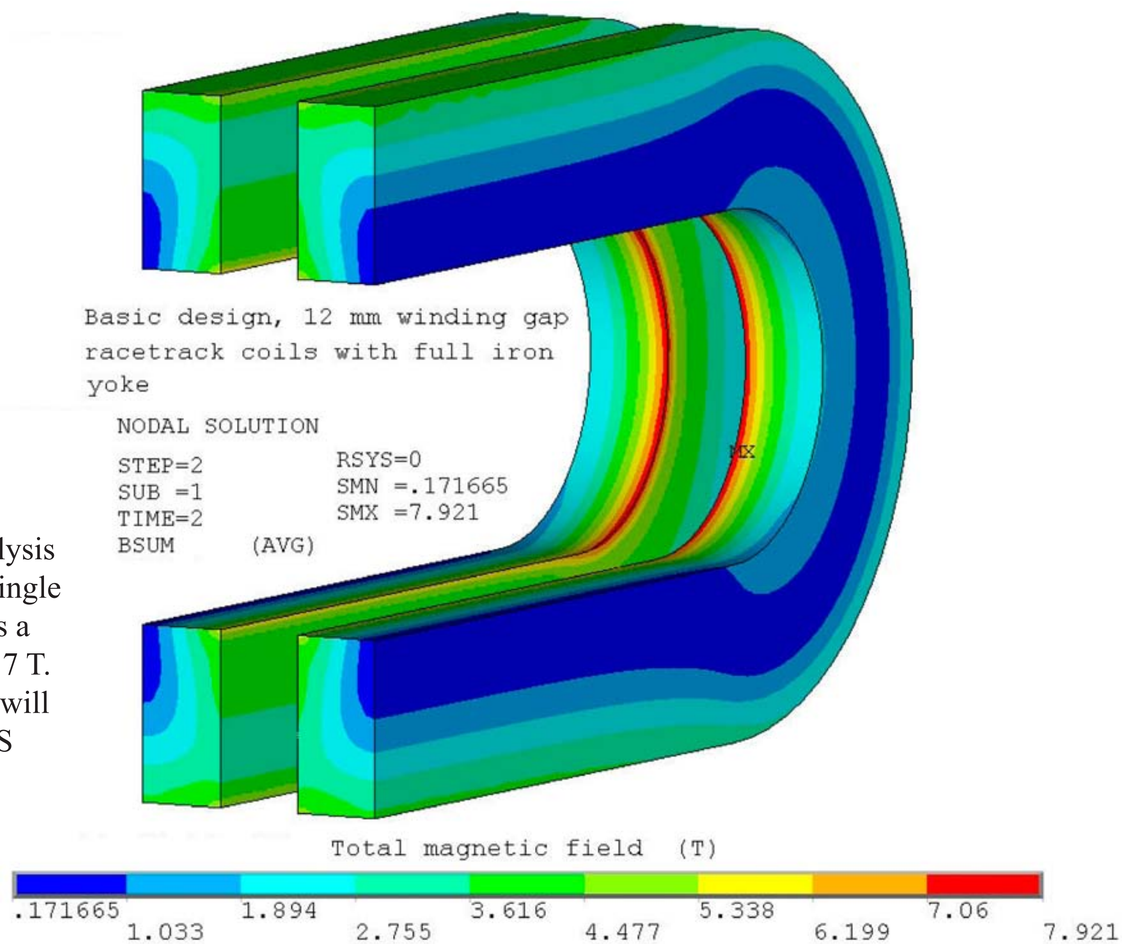


Figure 1. ANSYS analysis of the total field on a single racetrack pair indicates a maximum of just over 7 T. Eighty racetrack pairs will be required for the APS demonstration model.

higher fields within acceptable space and facility requirements. The feasibility study was successfully completed and led to a follow-on contract for the production of a demonstration model to confirm the Nb_3Sn, cryogenic and assembly concepts. The APS study is one example of how the expertise and collective resources within MS&T are being applied to introduce unique new superconducting magnet systems for the general benefit of science. For more information on this collaboration contact MS&T Engineer Huub Weijers (*weijers@magnet.fsu.edu*) who is leading the project.

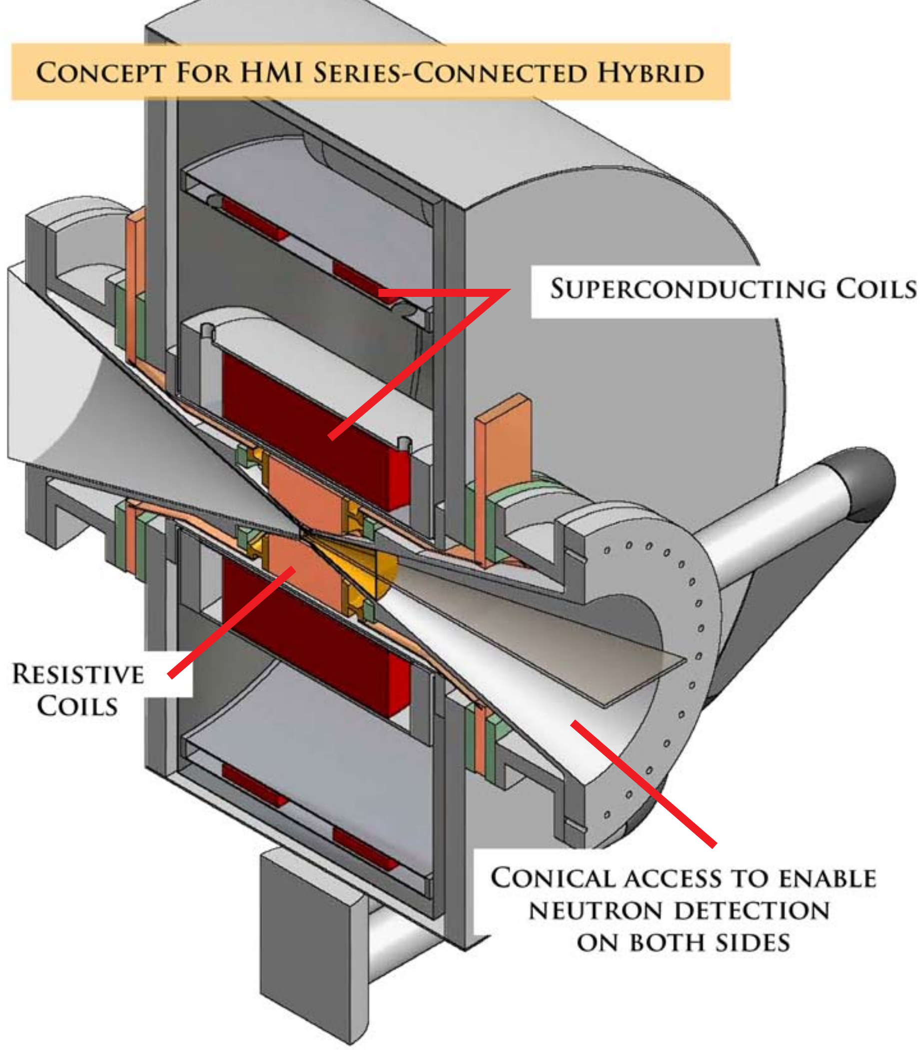


Figure 2. The HMI facility requires conical access to the center of the SCH to enable detection of the scattered neutrons.

The Hahn-Meitner-Institut (HMI) in Berlin, Germany, has contracted with MS&T division to study the possibility of installing a Series-Connected Hybrid (SCH) magnet system for neutron scattering experiments in a new facility called the Extreme Environment Diffractometer (EED). The unique combination of the NHMFL's world-leading resistive magnet technology and the cable-in-conduit superconducting technology successfully demonstrated on the NHMFL's record-setting 45 T Hybrid magnet is proving to be an attractive means for providing high magnetic fields at levels substantially greater than can be produced by solely superconducting magnet systems and much more economically than by all-resistive means. All-superconducting magnet systems are often attractive because of the minimal power required for operation, but they are presently limited to reliable production of less than approximately 21 T, on the other hand, the SCH concept can provide 40 T or more at power levels that are economically attractive, even at laboratories lacking the dc-power infrastructure of the NHMFL. Under the contract with HMI, MS&T is exploring the initial delivery of a system providing at least 25 T with the potential to upgrade to higher fields in the future. The field presently available at HMI in similar facilities is 15 T. We fully expect our SCH system to provide HMI with their most attractive option by far for a high-field, neutron-scattering magnet, which in turn will enable scientific exploration where no science has gone before. For more information on this collaboration, contact John Miller, director of MS&T (*miller@magnet.fsu.edu*), who is leading the project.

EDUCATION at the NHMFL

P. Dixon, Director, NHMFL Center for Integrating Research and Learning (CIRL)
C. Villa, CIRL

After another summer of exciting programs—Research Experiences for Undergraduates, Research Experiences for Teachers, high school students from the Regional Institute for Math and Science, Teachers in Residence, and a 40-teacher summer institute—the Center is gearing up for the new academic year. We are looking forward to several new programs as well as the continuation of our successful outreach to students, teachers, and the general public.

School outreach has always been a major mission for the Center and it continues anew in 2005-2006. After reaching a high mark and performing activities in over 250 K-12 classrooms in Florida, Georgia, and Alabama, new activities were needed to keep students excited about MagLab outreach. This year the Center will unveil several new outreach activities that aim to educate students more about the science that goes on here at the lab by using lessons that engage the students hands-on and make the concepts of magnetism and electricity easier to learn and remember. All of the Center's pre- and post-visit activities now include materials that correspond with standards set by the nation's No Child Left Behind act. These activities are available for download on the Center's Web site (*www.education.magnet.fsu.edu*).

The Center maintains formal partnerships with two local schools, one an elementary magnet school for science and math, and the second a middle school with a pre-International Baccalaureate program. We are expanding our partnerships to include a second middle school and two high schools. Teachers from these schools have developed a project to partner high school chemistry students with sixth graders—communicating with one another through science teams, sharing data, writing reports, and asking and answering questions—modeling real world science in the classroom.

A local high school will institute a "Godby High School Low Magnetic Field Laboratory" patterned on the MagLab's user program. Students will submit proposals to conduct research in an area set aside for magnet-related explorations. Scientists from the MagLab will provide input on some projects and students from the high school will make several visits to the MagLab to meet with scientists and learn how magnets are used in real-world scientific research.

Pat Dixon, Director of CIRL, and Ryan Wilke, Graduate Research Assistant, have completed the first of **two research projects on the impact teachers participating in Research Experiences for Teachers programs have**

on students. *Linking In-service Teachers' Participation in a Research Experience to Students' Attitudes toward Science* has been submitted for publication and for presentation at the National Association for Research in Science Teaching conference in Spring 2006. The second study, which investigates elementary teachers' thinking and practice after they participate in a RET program, is ongoing and will be completed by Spring 2006.

Two local teachers, Richard McHenry from Leon High School and David Rodriguez from Swift Creek Middle School, worked at the Center for six weeks to develop the **Geophysical Information for Teachers workshop** for the winter American Geophysical Union conference. The activities that were developed are designed for middle and high school teachers to expand their knowledge of earth science concepts, to hear from scientists about new research in the earth sciences, and to bring back hands-on inquiry activities for their students. Working with Dr. Vincent Salters (Magnet Lab Geochemistry Group), Richard and David found a way to take current research topics and bring them into the classroom. Often information found in middle school and high school earth science textbooks is out of date or does not include current findings. **The GIFT workshop fills in the gaps.**

The Center kicks off its fall activities with exhibits at the Challenger Learning Center and the Mary Brogan Museum of Art and Science, both in Tallahassee. In addition, the Center hosts 50 to 75 elementary, middle, and high school teachers for the fall Ambassador Meeting that will feature reports from teachers on science-related activities they attended during summer 2005. Ambassador meetings typically attract teachers from a five-county area who come to the MagLab to share strategies, participate in workshops, and hear guest speakers to enhance classroom science. Ambassadors return to their schools and districts to disseminate best practices in science education and information about Center activities.

Pat Dixon will participate in the Pan-REU Workshop in Washington, D.C. in September. Organized by Randy Duran at the University of Florida, the Pan-REU Workshop will bring together 60 university and center REU program managers to discuss a number of issues including the impact of REU programs, at the national level, on students, and strategies and models of assessment of REU sites. Carlos R. Villa will be attending and presenting at the Florida Association for Science Teachers in Orlando, Florida, and at the National Science Teachers Association's national conference in Anaheim, California. At these conferences, he will present magnet-themed activities that have been used at the lab with teachers from around the nation. Center educators plan to participate in a number of conferences in the 2005-2006 academic year to make presentations and to meet with other education and public outreach professionals. The considerable network of informal science education professionals provides a broad look at how outreach is conducted in diverse venues. We look forward to interacting with teachers, researchers, scientists, and outreach professionals at the Florida Association of Science Teachers, National Science Teachers Association, Association for Science Teacher Education, National Association of Research in Science Teaching, and the American Geophysical Union conferences.

News From LANL

Los Alamos 100 T Multi-Shot Magnet Poised to Explore New Parameter Space in 2006

D. Rickel, NHMFL/LANL
A. Migliori, NHMFL/LANL
J. Singleton, NHMFL/LANL

It is a popular statement amongst scientists that a factor-of-two change in a thermodynamic variable doubles the number of new physical phenomena; however, thermodynamic variables that can be controlled—temperature, pressure, magnetic field, and electric field—are very few in number. The entire useful ranges of temperature (from μK to sample vaporization) and electric field (from well below the noise floor to catastrophic dielectric breakdown) are already routinely accessed. Although pressures available to present technology (diamond-anvil cells) are in the Mbar range, the types of measurement that can be carried out are restricted. Nevertheless, pressure-induced phase transitions proceed via mechanisms associated with electronic bandwidth and gap changes, structure symmetry, and more, and there is a vibrant effort to push laboratory-accessible pressures as far as possible.

The thermodynamic variable of concern here, magnetic field, is different from others because it has a twofold effect: it provides a ***tunable electronic energy scale, and a tunable nanosize lengthscale.*** Magnetic fields can act as negative pressure, so that all of the above-mentioned physical effects associated with electronic bandwidth, gap changes and so on can be studied, but from a different starting point.

Pressure and magnetic field, unlike temperature and electric field, are currently technologically-limited. The Los Alamos 100 T multi-shot magnet (100TMSM) represents a new technological limit. Its magnetic field will provide routine non-destructive access to stronger thermodynamic effects than any other thermodynamic variable but temperature (100 T = 134 K). In contrast to elevated temperatures, where "thermal smearing" obscures the fine detail of electronic energy levels; however, magnetic fields can be applied at any temperature, allowing explicitly-quantum phenomena to be observed. Moreover, the 100TMSM's millisecond measurement times permit the application of a wide variety of experimental probes including spectroscopy (continuous and time-resolved), Fermi-surface measuring techniques, thermal properties, and the Hall effect.

Many of the above-mentioned experimental probes are not generally possible in the destructive, microsecond-duration magnetic fields that are the only other feasible route above 100 T. With the 100TMSM, the sample, magnet outsert and cryostat are designed to survive thousands of pulses, and each pulse lasts thousands of times longer than in other 100 T magnets. The effects of these advances are crucial, and threefold. First, there is the ability to repeat a measurement at 100 T without replacement of any magnet components. Second, the three-order-of-magnitude increase in pulse duration vastly reduces eddy-current heating in metals. Third, the increased time at field, though still short by some standards, is, surprisingly, long enough to enable certain micro-technology-based sophisticated approaches to the measurement of specific heat and thermal conductivity.

The 100TMSM is becoming a reality at the NHMFL pulsed field facility at Los Alamos. Attaining 100 T as a user magnet is a lofty goal and is only made possible by significant advances in pulsed magnet design and an adequate power supply that can produce a large volume background field. Taking advantage of the 1.4 GW Los Alamos generator, the Los Alamos engineering team

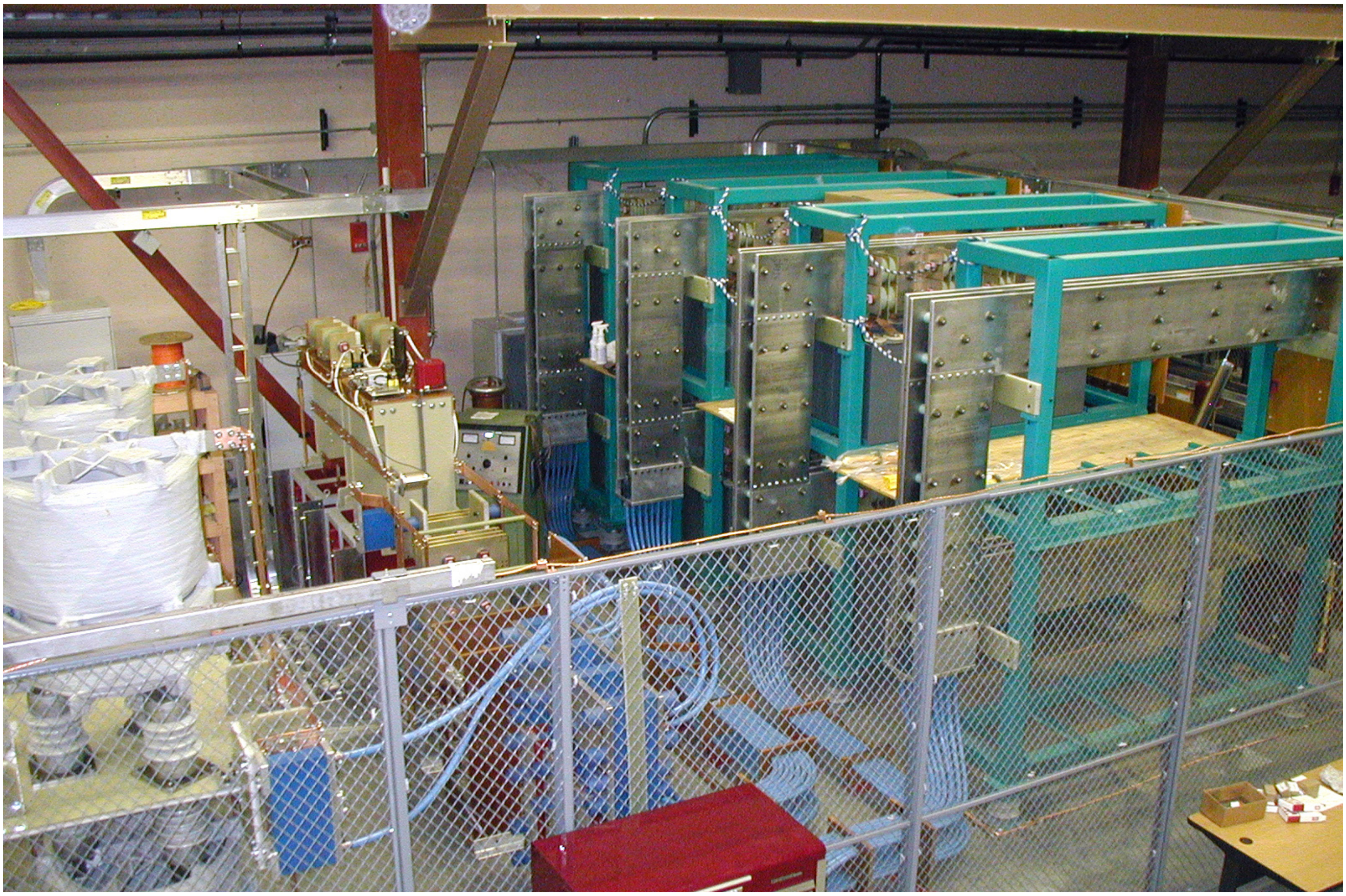


Figure 1. View of the operational 100 T capacitor bank.

designed a large volume outsert that can accommodate a high field insert magnet. The insert magnet is under design by the NHMFL-Tallahassee Short Pulse Design Group and incorporates impressive advances made by that group over the past few years. The insert magnet will be powered separately by a 2.2 MJ capacitor bank.

Progress on the 100 T system first impacted NHMFL's science programs with the successful construction and operation of the insert magnet capacitor bank (see the article by Scott Crooker in the previous *NHMFL Reports*, Vol. 12, No. 3, pg. 9). This has been followed by the near-completion of the engineering design and large-parts fabrication for the outsert magnet. Several large coils have reached Los Alamos, with the remainder due in September. Assembly of the outsert will begin in October, with outsert testing to start in May 2006, followed by overall system tests in June 2006.

The insert work is progressing well with the successful testing of two prototype designs that have led to operational 65 T and 75 T user magnets. In early December, the insert design will be tested for final modifications at the stress level predicted for 100 T operation.

To date the Los Alamos team has:

(1) Demonstrated the load carrying capabilities of the high-strength over wrapped stainless steel shells for the outsert windings.
(2) Tested the capacitor bank to 110 kA verifying that operation at the nominal 50 kA is assured.
(3) Made repetitive insert tests of over 100 shots at 70 T and 14 shots at 75 T without failure, verifying modeling predictions.

New Grants Open Doors of Opportunity

HBCU/NHMFL Collaborative DOE Research on d- and f-electron Materials

Two historically black universities, Prairie View A&M University (PVAMU) and North Carolina A&T University (NCAT), are pleased to announce the full funding of a $1.5 million one-year collaborative grant with NHMFL's Extreme Conditions Group under DOE's National Nuclear Security Administration (NNSA). The award will serve to establish and enhance strong research opportunities at the two historically black colleges and universities (HBCUs) while extending NHMFL's currently funded DOE research that utilizes pressure, temperature, and magnetic fields to probe the actinides and related material. The team of researchers includes the PI, Prof. Kevin Storr of PVAMU; Prof. Orion Ciftja, also of PVAMU; Prof. Abebe Kebede of NCAT; and Stan Tozer, Tim Murphy, and Eric Palm of the NHMFL. The collaboration will focus its experimental and theoretical efforts on the physics of d- and f-electron materials. An important aspect of this effort is sample fabrication and high quality crystal growth, portions of which will be carried out with guidance from Jim Smith and Jason Cooley at LANL.

A 16 T Quantum Design PPMS system to be housed at NHMFL/TLH will provide the initial anchor for HBCU participation at the lab. The collaborative effort will also utilize the 16/18 T dilution refrigerator system that was purchased for the existing DOE effort. The NHMFL will provide lab space and the expertise to help graduate and REU students in their research. Should Congress appropriate funds to extend this new program at DOE, the two groups hope to expand the effort over the course of the next few years and bring in additional HBCU institutes, focusing on experiments of mutual interest.

The samples for the research will be grown at NCAT and LANL by Professor Kebede and his students with funds being provided for materials and equipment. At PVAMU, a 15/16 T superconducting magnet with helium-3 capability will be installed along with various electronics and equipment for initial measurements. A funded PVAMU condensed matter theorist will also contribute to this effort.

The grant will support five students at PVAMU, two students at NCAT, and six students in the summer REU program at NHMFL. Travel funds have been allocated for professors and students to extend the collaborative research to NHMFL/TLH and the pulsed magnetic field facilities at LANL. Travel support will also be provided for conferences and extended stays at NHMFL and LANL during the academic year and the summer.

Our goal is to increase the involvement of underrepresented minority scientists and their students in cutting-edge research critical to the NNSA. This collaborative effort will add to the number of researchers who can eventually be hired by DOE labs to help ensure our national security through research.

EMR Awarded Grant for the Concept and Engineering Design of a Free Electron Laser (FEL) Light Source

We are extremely pleased to have been awarded a grant for the Concept and Engineering Design of a Free Electron Laser (FEL) light source for research in high magnetic fields. This $1.8 million project addresses the unique scientific opportunities that result from combining the existing suite of magnets at the NHMFL with a flexible photon source in the infrared to terahertz regime. Flexibility in intensity, pulse duration, and use of multiple photon beams in a pump-probe geometry all combine with the continuous tuning of the magnetic field as a thermodynamic parameter to address a broad range of questions in materials of interest in condensed matter physics, chemistry and biophysics, including probing dynamical processes in these materials under extreme conditions.

When realized, this facility will be unique in its combination of high magnetic fields and intense electromagnetic radiation. The proposed frequency range spans the spectral region corresponding to energies of 5 cm-1 to 5000 cm-1 (2000 µm to 2 µm), which covers the majority of electronic excitation and interaction energies that are encountered in high-magnetic field research at the NHMFL. This combination of tuneability and power over a very wide frequency range can presently not be realized by any other light source. Simultaneously, the short relativistic electron bunches will provide broadband coherent synchrotron radiation at frequencies up to 3 THz, which can be employed in combination with narrowband laser pulses from 0.2 to 200 THz. This addresses an energy range that is especially important in high-magnetic field research.

The partners of the NHMFL in the project are the Free Electron Laser group of Jefferson Laboratory and the Center for Terahertz Science and Technology at UCSB. The Jefferson group currently runs a FEL delivering the world's highest average laser power. It is based on a superconducting linear accelerator and operates in the wavelength range of 14 to 1.5 µm. The Santa Barbara group operates the world's most versatile FEL in the low frequency range (2500 µm to 63 µm). We believe that these two successful programs will provide the technical know-how and engineering experience that are necessary for the design and construction of a reliable FEL system for high magnetic field research, while experiments will be conducted at both facilities to optimize the design. The realization of a free electron laser as a flexible source of intense IR-to-THz radiation *in combination with high magnetic fields* will open new scientific regimes, develop new experimental techniques, and support the research of scientists nationwide. If you are interested in the possibilities that this FEL will offer, we encourage you to contact any of the PIs (Johan van Tol, John Singleton, Louis-Claude Brunel, Greg Boebinger, and Nancy Greenbaum).

FAMU / MS&T Instrumentation Award

Peter Kalu (PI), along with Teng Ma, Ke Han, Anter El-Azab, and Namas Chandara (Co-PIs), received a $766,000 Materials Research Instrumentation award from NSF. The proposal was titled "Acquisition of a Field Emission (FE) Scanning Electron Microscope (SEM) for Nano-texture and Nano-structure Characterization."

At present, the Materials Science research and education program and the number of Materials Science faculty and scientists at the FAMU-FSU College of Engineering and NHMFL are growing rapidly. The overall materials research activity at FAMU and FSU comprises several research groups and laboratory facilities in which strong collaboration and synergy among various faculty/programs are taking place. In spite of the multitude of materials research facilities on both campuses and at the NHMFL, there is a noticeable absence of nanoscale characterization capability, specifically, a state-of-art microscope that can be accessible by both senior researchers and students. In fact, new curriculum and research programs in nanoscale science and engineering that focus on synthesis, characterization, and simulations of nanoscale materials systems are being developed. A high resolution SEM with nanoscale resolution capability is vital to the overall research activities at the three institutions. This instrument can magnify 1.5 million times and will enable one to study features as fine as 10 thousandth of human hair. The instrument will provide useful capabilities for other research projects in Industrial Engineering, Electrical Engineering, Chemical and Biochemical Engineering departments, as detailed in the proposal. The acquisition of this miscroscope will enhance the diverse materials efforts at FAMU, FSU, and the NHMFL and provide a cohesive base for the multitude of interdisciplinary research activities among these three institutions.

Some of the research projects that will benefit from the FE-SEM acquisition include development of high strength nano-composite conductors for basic research and applications; synthesis and characterization of CNTs; fundamental studies of alloy deformation; magnetic field alignment of $Bi_2Sr_2CaCu_2O_8$ superconductors; and synthesis, characterization and modeling of CNT based copper composites for heat sink applications in computer CPUs. The functionality provided by the FE-SEM is currently not available in our facility. This includes imaging, texture and composition characterizations in nanoscales.

People in the News

Celicia Bell, coordinator and an editor of this newsletter, received her Master's degree in English Education from Florida State University on August 6. She worked toward this goal over a period of two years, while holding down her full-time job with the Magnet Lab and while being "Jasmine's Mom." This fall, Bell will tackle a new challenge when she begins teaching freshman composition during evening classes at Tallahassee Community College. Helping students who "didn't get it" in the K-12 years is her passion: "Reading, critical thinking, and good writing skills are essential to nearly every job or career. This may be the last chance for some of these students, so it's an opportunity to help that I'm very excited about."


Celicia Bell

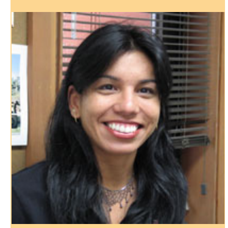
Eun Sang Choi has joined the NHMFL Instrumentation and Operations Group as an Assistant Scientist. He will be continuing his already active high magnetic field research, developing new and improved instrumentation for magnetic measurements, and supporting users. Choi did his undergraduate and graduate work at Seoul National University. His thesis work on magnetotransport properties of doped polyacetylene was supervised by Professor Yung Woo Park, a long-time NHMFL user. In fact, Eun Sang did some of his thesis work at the NHMFL. After postdoctoral work with Prof. Woun Kang of Ewha Womens University in Seoul, Eun Sang came to the NHMFL full time for postdoctoral work with Professor James Brooks. His career as a postdoc has already been unusually productive. Choi has used electrical and thermal transport techniques at ambient and high pressures to study polymers, carbon nanotubes, and the ubiquitous organic charge transfer salts and other highly correlated electron systems. He has extensive experience with torque and vibrating sample magnetometry. Eun Sang will be improving existing magnetic measurement techniques and developing new ones in the DC Field Facility, focusing especially on ways to obtain the absolute values of very small moments.


Eun Sang Choi

Kristina Hakansson, a former postdoctoral researcher in the NHMFL ICR Program, has been designated the Dow Corning Assistant Professor at the University of Michigan. The distinction carries $30,000 a year in research support.


Kristina Hakansson

Ana Lima is a new postdoc at NHMFL/LANL. She received her B.S. in Physics with distinction at the State University of Rio de Janeiro. In 1997, she finished her Masters thesis in Astrophysics at the National Observatory. From 1999 to 2001, she was a Ph.D. student at the Brazilian Center for Research in Physics with Dr. I.S. Oliveira, working with magnetically anomalous intermetallic systems using both theoretical and experimental approaches. After finishing her Ph.D. thesis, Lima joined Professor Gschneidner's group at Ames Laboratory, Iowa State University, developing theory to explain anomalous magnetocaloric effects. By the end of 2003, she moved to MST-10, LANL, to work with nanostructured materials (mainly, thin films and nanoparticles). Recently she joined the NHMFL to work with John Singleton performing pulsed field experiments. She is also interested in length scale effects on magnetic properties of materials. Presently, she has collaborations with five institutions in three countries.


Ana Lima

Jacob Moore, a graduate student working in the NMR Program, has received a Ruth L. Kirschstein National Research Service Award Individual Fellowship from the Public Health Service. Moore is working in the laboratory of Professor Timothy A. Cross on the solution NMR spectroscopy of membrane proteins from *Mycobacterium tuberculosis*. Among several proteins that Moore and another graduate student, Richard Page, are working on is Rv1761c. This work represents a collaboration with the research group of Professor Stanley J. Opella at University of California at San Diego.


Jacob Moore

HAU B. NGUYEN

Hau B. Nguyen, a graduate student in the NMR program, has received an American Heart Association Predoctoral Fellowship with a proposal entitled *"Structural Analysis of Integral Membrane Proteins from Mycobacterium tuberculosis—A Major Cause of Pericarditis Disease."* Nguyen is working in the laboratory of Professor Timothy A. Cross on the solution NMR spectroscopy of two small transmembrane proteins, Rv1567c and Rv1861, each of which has two transmembrane helices.

SUSAN RAY

Susan Ray has been appointed Director, Public Affairs for the NHMFL. Prior to joining the Magnet Lab, Ray was Vice President of Ron Sachs Communications. Her background includes progressive advancements to executive-level responsibilities for communications and media strategies—print, television (including a 30-min show), radio, and Web. A long-time resident of Tallahassee, she worked at the *Tallahassee Democrat* as an editor on the business and news desks and created, edited, and launched "Living Here," a guide to living in the Tallahassee area. In the category of "it's a small world," Ray designed a Business Wednesday section at the *Democrat* that featured the late Jack Crow, founding director of the laboratory.

Ray, a graduate of FSU, is an extraordinarily talented, highly skilled professional with an extensive base of experience. She brings expertise, knowledge, and judgment that will allow her to make immediate contributions to the NHMFL. Ray says that she is "delighted to play an integral role in giving the Magnet Lab the high profile and esteem it so richly deserves—on the local stage and far beyond."

IN MEMORIUM

PETER MURPHY

Peter Murphy, of the Instrumentation and Operations Group, passed away on June 10. Murphy started work at the NHMFL in October, 1993. His contributions to the lab's mission were all in the area of electronic systems design and trouble-shooting, but within that broad area his efforts were very varied. He designed extremely small circuits for processing very high frequency (1 to 2000 MHz) signals, as well as the magnet protection circuits for the two largest superconducting magnets at the NHMFL. Most of his designs were for unique circuits needed by individual researchers at the lab. Some, worked out in collaboration with the scientists in Alan Marshall's Ion Cyclotron Resonance (ICR) group, have been sold to other ICR researchers.

Murphy taught student interns from Taylor County Technical school in Perry, FL, Thomas Technical Institute in Thomasville, GA, and the FAMU/FSU College of Engineering, as well as many graduate students, undergraduate summer students, and K-12 teachers working on projects during summer programs.

One of Murphy's responsibilities was trouble-shooting and improving the power supplies that provide current for the strongest magnets at the NHMFL. This was a continual process of improving reliability and field quality punctuated by crises when something major went wrong. He was always calm and thorough when analyzing problems, working systematically to a solution. He was working with colleagues on a major upgrade to the power supplies when he died.

Murphy was always a pleasure to work with. He was an excellent supervisor and mentor for those who reported to him in his role as head of the Electronic Instruments Shop. He will be sorely missed, personally and professionally.

2005—Busy Year for Conferences

5th North American FT-ICR Mass Spectrometry Conference

The 5th North American Fourier Transform Ion Cyclotron Resonance Mass Spectrometry Conference was held at the Double Tree Grand Key Resort Hotel in Key West, Florida, **April 17 to 20, 2005**. Organized by the Magnet Lab's Dr. Mark Emmett and Ms. Karol Bickett, the conference attracted 115 leading researchers from the United States, Austria, China, Croatia, England, Denmark, Germany, Hungary, Korea, Russia, Sweden, and The Netherlands, who presented research on new advances in the field. The invited presentations ranged from instrumentation to technique development in the biological/biomedical sciences spanning pharmaceutical metabolism to proteomics, environmental analysis, and petroleomics, with special emphasis on new developments.

Generous sponsorship by Advion BioScience, Bruker Daltonics, Florida State University Department of Chemistry and Biochemistry, IonSpec, Oxford Instruments, Siemens, and ThermoElectron Corp. made it possible to provide registration and four nights lodging for all invited speakers as well as 19 student awards for poster presentations. The conference fee of $400 ($100 for students) included registration, a welcoming reception, and most meals. The technical program featured 44 posters and 25 invited speakers, concluding with a plenary lecture by the Magnet Lab's Alan G. Marshall, on "Connections and Luck: The Basis of FT-ICR Mass Spectrometry." This Conference has become a primary forum for presentation of the latest and best developments in the field.

A Workshop on a 30 T High Resolution Magnet for NMR Spectroscopy and Imaging

A very successful workshop was held at the NHMFL in the afternoon following the celebration for the opening of the Ultra-Wide Bore 900 MHz User Facility on **July 28**. This workshop on the prospects for a 30 T or 1.3 GHz NMR magnet was inspired by the laboratory's success with the new high resolution 900 MHz magnet, the 5 T High Temperature Superconducting (HTS) coil that was tested to 25 T using a 20 T background field, and the Report by the Committee on Opportunities in High Magnetic Field Science (COHMAG) commissioned by the National Academy of Science. The workshop comprised three short sessions focusing on the scientific justification for such a magnet, a technological justification for this magnet, and a justification for citing the project at the NHMFL, along with a brief outline for implementing this vision.

The scientific vision was delivered by Professor Gerhard Wagner from Harvard Medical School who spoke about advancing solution NMR spectroscopy of biological macromolecules and macromolecular complexes. Dr. Paul Ellis from Pacific Northwest National Laboratory spoke about observation of metals and quadrupolar nuclei in biological complexes while Prof. Stanley Opella from UC San Diego discussed advantages of high fields for structural characterization of membrane proteins through solid state NMR. Finally Prof. Andrew Webb from Penn State University discussed the advantages and challenges of doing magnetic resonance microscopy at 30 T.

Denis Markiewicz, the project leader for the NHMFL's Ultra-Wide Bore 900 MHz Magnet, initiated a discussion of the technical justification that represented initial efforts toward a conceptual design, evaluation of both low and high temperature superconductors, cryogenic options, persistence and a range of other topics. Prof. Justin Schwartz, the NHMFL project leader for the world record 5 T HTS magnet expanded on a description of state-of-the-art high temperature superconductors. Thomas Painter presented a preliminary timeline for the design and construction of a 30 T magnet and Dr. John Miller discussed the diversity of skills present at the NHMFL that would be brought to bear on such a project.

A diverse audience representing funding agencies, including the National Science Foundation and the National Institute of General Medical Sciences, as well as wire, magnet, and NMR manufacturers was present. It is clear that such a project should garner resources from several funding agencies and potentially other public and private sources. In addition, we are planning on developing a very close working relationship with the private sector. Following advice in the COHMAG report, mentioned above, the NHMFL is interested in pursuing prospects for building several magnets to distribute development costs, to enhance opportunities for working with the private sector, and to distribute and expand user facilities originating from this technological development.

Physical Phenomena at High Magnetic Fields - V

One hundred researchers from around the world descended on Tallahassee in early August for five days of discussions on a wide range of areas in which magnetic fields play a role. Topics ran the gamut: from semiconductors and magnetic materials to biochemistry and quantum computing. Nearly forty FSU and Magnet Lab faculty members also participated in this prestigious meeting, which is a major forum for assessing current research, new experimental techniques, and promising applications of high magnetic field science.

The Conference on Physical Phenomena at High Magnetic Fields was initiated by the laboratory in 1991 and gained international stature in 1995 when Nobel laureate, Magnet Lab Chief Scientist, and FSU Eminent Scholar Robert Schrieffer assumed chairmanship. PPHMF-III in 1998 attracted newly-minted Nobel laureates, Horst Störmer and Robert Laughlin, and PPHMF-IV was hosted by Magnet Lab partner, Los Alamos National Laboratory, in 2001. This year's PPHMF-V was chaired by FSU Associate Professor Nicholas Bonesteel.

FSU President T.K. Wetherell opened PPHMF-V on **August 5, with sessions lasting through August 9**. The conference was pleased to host researchers from Stanford, Harvard, Cornell, Georgia Institute of Technology, and many other major U.S. universities, as well as from laboratories and institutions worldwide.

International Conference on Low Temperature Physics

The University of Florida hosted the 24th International Conference on Low Temperature Physics in Orlando from **August 10 to 17**. This is the premiere gathering of the low temperature community held every three years and sponsored by the International Union of Pure and Applied Physics. The first conference was in Cambridge, Mass. in 1949. The last LT—LT23—was held in Hiroshima, Japan and LT22 was held in Helsinki, Finland. About 1,000 participants at LT24 enjoyed 196 oral presentations and about 1,100 posters during the week on subjects ranging from cosmology (it's all in the superfluid ^{3}He) and dark matter detectors to superconductivity, the quantum Hall effect, and super solid ^{4}He (or is it?).

For the first time, both the London and Simon Prize lectures were on the opening day of the conference. Very enlightening and entertaining talks were given by award winners Richard Packard, Sebastien Balibar, J.C. Seamus Davis, and Grigory Volovik.

The entire conference was in the Hilton at Walt Disney World Resorts, with mid-morning breakfast, lunch, and afternoon drinks and snacks provided to the participants free of charge. The biggest commercial exhibit (25 booths) ever assembled for an LT conference included companies from all over the world. The Friday night outreach lectures were by Nobel laureate Doug Osheroff, on the Columbia disaster, and Chief NASA Engineer Rex Geveden, on the Year of Einstein Gravity Probe B experiment. About 300 people went to Kennedy Space Port on Sunday and many had lunch with an astronaut. At the banquet, there was dancing to the Frank Sullivan sextet with vocalist, a Gainesville group with Grammy Award roots.

International Conference on Ultra Low Temperature Physics

About 140 physicists from 12 different countries gathered in Gainesville to discuss and share their new results at the International Conference on Ultra Low Temperature Physics (ULT-2005). This event was held in the New Physics Building of the University of Florida from **August 18 to 20** as one of the satellite conferences following the International Conference on Low Temperature Physics (LT-24). Participants were greeted at the reception on August 17, in the evening, at the Florida Museum of Natural History. More than 100 papers were presented in 11 oral and 2 poster sessions and lively discussions were exchanged in and out of the sessions. The scientific program covered unusually broad research areas in ultra low temperatures. Quantum phase transitions, low temperature particle detectors, and quantum devices were new topics presented during the conference, along with the traditional ULT topics such as superfluids, quantum solids, and nuclear magnetism. In addition to the regular program, a special discussion session on supersolids was held on August 18. Various theoretical ideas and details of recent experimental results on this subject were discussed until 9:30 p.m. The National High Magnetic Field Laboratory was one of the major sponsors for this conference. ULT-2002 was held in Kanazawa, Japan, and the next ULT is planned to be held in London in 2008 right after LT-25 in Amsterdam, The Netherlands.

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CONFERENCES & WORKSHOPS

8th International Symposium on Magnetic Suspension Technology
http://www.ifw-dresden.de/imw/ISMST8/
September 26-28, 2005
Dresden, Germany
Contact: Hans Schneider-Muntau
smuntau@magnet.fsu.edu
850-644-0863

NHMFL Users' Committee Meeting
October 28-29, 2005
Gainesville, Florida
University of Florida
Contact: Merry Ann Johnson
johnson@magnet.fsu.edu
850-644-6257

Free Electron Laser Workshop
October 27, 2005
Gainesville, Florida
University of Florida
Contact: Hans Van Tol
vantol@magnet.fsu.edu
850-644-1187

Southeastern Section of the American Physical Society (SESAPS)
http://www.phys.ufl.edu/sesaps05.html
November 10-12, 2005
Gainesville, Florida
University of Florida
Contacts: Alan T. Dorsey & Paul Avery
sesaps2005@ufl.edu
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