HAPPY BIRTHDAY!

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This year’s External Advisory Committee (EAC) and User Committee (UC) meetings have recently passed. The less structured — and delightfully blunt — discussions with the EAC provide perspective and help develop an updated vision and set of priorities for the lab. The UC represents the customers, so their input on project prioritization, infrastructure plans, and user needs is invaluable. We welcome longtime user Jan Musfeldt of the University of Tennessee-Knoxville as the new chair of the User Committee, and deputy chairs Roy Goodrich and Tatyana Polenova.

One way we Think Big at the MagLab is through Big Magnet projects. Top-of-mind presently are the completion of the long awaited Split Magnet and the next assault on 100 T, both scheduled for mid-2011.

The Split Magnet, key pieces of which are shown above, is being constructed in our magnet shop as I type. Its specifications describe unprecedented line-of-sight to the sample for a high-field magnet, a daring design that several machine shops declined to fabricate, claiming in several cases that the key central piece was “impossible to machine.” We’ve machined the impossible, but discovered that we’re really pushing the state of the art for electric discharge machining. We’re confident that its innovative design will greatly strengthen the lab’s optics research, particularly for femtosecond pump/probe, Raman and terahertz spectroscopies.

The next assault on 100 T involves an advance in the smaller, capacitor-driven insert coil, enabled by more ductile magnet wire in the mm cross-sectional dimensions required. The present multi-shot magnet is routinely operated at 85 T, and has survived several 89 T shots. We are confident we can make a huge/substantial/noticeable step toward 100 T with the new insert. The following phase will involve re-engineering several coils in the large, generator-driven outsert magnet, enabled by successful fabrication of high-strength copper-niobium conductor in the cm dimensions required. We’re confident that we’ll be able to test the magnet at 95 T this coming spring.

Big Magnets exist to enable Big Science. In this issue, we feature a summary of the many scientific successes of the 900 MHz ultra-wide-bore (105mm) magnet. Users of this MagLab-designed and built magnet benefit from the MagLab’s unique probes and techniques. I think you’ll agree that the “900” has been a huge scientific success.

Rock and roll from the Big Director,

Gregory S. Boebinger
Graphene, early career PIs drive spike in new users

The Magnet Lab is accustomed to welcoming longtime users year after year, but a combination of emerging fields of study and interest by early-career scientists has led to a spike in the Magnet Lab’s percentage of new principal investigators.

2010 is on track to be a banner year in terms of new users for three reasons, according to DC Field User Program Director Eric Palm: exciting science, effective outreach and strong support for ex-students and former postdocs returning to the lab as independent researchers.

Emerging fields of study such as graphene and topological insulators are attracting scientists who haven’t worked in high fields before. Seventeen different user groups studied graphene in 2009, and interest in the material, growing for almost three years, shows no signs of abating.

“Graphene just begs to be put in a magnet, whether to learn about its fundamental science or potential applications. Graphene is one of those marriages of new science and exciting technology that causes an explosion of interest,” Palm said, adding, “There are many interesting ways to work with graphene, but in my opinion none so illuminating as high magnetic fields.”

One of the most reliable sources of new users are the students and postdocs who, after working with lab staff or longtime users, keep up their collaborations after they’ve graduated or started their own projects. Familiarity with the lab’s tools and techniques, combined with the freedom to explore their own research goals, make these “new” users adept collaborators and canny investigators into how emerging fields can be explored utilizing high field magnets.

Graphene and quantum oscillations are the two areas of interest drawing users to the Magnet Lab’s Pulsed Field Facility, which saw more new users in 2009 than any other Mag Lab user program. A new generation of students and postdocs maintaining their relationships with the PFF has also bolstered the group’s numbers.

“In some condensed matter physics cases, the most extreme magnet systems are necessary to reveal the complete picture. Reaching beyond 45 or even 100 tesla is necessary when magnetic interactions or electron scattering rates compete

Figure 1.
Rice University graduate student Layla Boosheri, from Professor Jun Kono’s group, has been collaborating with the Pulsed Field Facility’s Chuck Mielke to investigate the magneto absorption of single-layer graphene in magnetic fields up to 170 tesla using the lab’s Single Turn coil. The magneto absorption measurements reveal a wavelength-dependent resonance at high magnetic fields, allowing the researchers to pinpoint the Fermi energy of the doped graphene.
with thermal energies that may mask the intriguing physics that drive us,” said Pulsed Field Facility Director Chuck Mielke. “The PFF is the answer to our users who need the extreme in high magnetic fields.”

Last year, the Magnet Lab streamlined its user application process with the introduction of a web portal that standardized requests for magnet time across all seven user programs. To learn more about becoming a user at the lab, visit users.magnet.fsu.edu.

**INTERVIEW WITH A NEW USER**
Chun Ning (Jeanie) Lau
University of California, Riverside

**WHAT HAS YOUR EXPERIENCE AS A MAG LAB USER BEEN LIKE SO FAR?**
I have enjoyed my experience at Mag Lab so far. I think it’s very well run, and my host here, Dmitry Smirnov, is exceedingly helpful. Most of our requests (e.g. making new BNC breakout boxes and acquiring new voltage amplifiers) are accommodated. Of course we are always stressed during our limited magnet time, but I certainly think the “southern hospitality” makes our stays at Tallahassee very pleasant (well, as pleasant as the tight schedule allows).

**WHAT IS IT LIKE TO WORK ON GRAPHENE DURING THIS EXCITING TIME?**
Working on graphene has been at once stimulating, exciting, fun and nerve-wracking. A lot of talented people are working in this field, and progress is announced weekly, sometimes daily. It’s easy to be “scooped” (hence nerve-wracking); on the other hand, there are so many interesting ideas, proposals and angles that one can explore, and it’s wonderful.

**WHAT IS IT ABOUT THE COMBINATION OF GRAPHENE AND HIGH FIELDS THAT YIELDS SUCH INTERESTING RESULTS?**
I think graphene is a unique system: it’s a surface 2D electron system, so that one can perform optical, scanned probe and mechanical measurements in addition to transport studies. It also has a special symmetry (SU(4), for spin and valley degrees of freedom) that gives rise to special fractional quantum Hall states that are absent in traditional semiconductor devices. It is a thin membrane so that its morphology is coupled to its electronic properties. It’s also readily available to anyone with a scotch tape and a microscope (and I’ve always called it a “poor man’s or woman’s 2DEG”). All of these make graphene a fascinating system to study and explore.

**Figure 2.**
By subjecting high mobility bilayer graphene (lower inset Figure 2a) to magnetic fields in excess of 25 tesla (T), the complete lifting of this eightfold degenerate LL can be observed. As shown in Figure 2a, the Hall conductance at the lowest field displays the $\nu=4$ and $\nu=4$ filling factors that mark the initial degeneracy. As the field is increased, new plateaus emerge as successive symmetries are broken, with plateaus eventually appearing at each filling factor. These new filling factors also can be detected through the measurement of new resistance minima in the longitudinal resistance. By examining the behavior of these minima as the magnitude and direction of the applied field is changed, information about the origin of the symmetry breaking that underlies each new plateau can be gained. In particular, the sensitivity of the minima at $\nu=2$ & 3 to the perpendicular component of the applied field rather than to the total field (Figure 2b) indicates that these states are not formed by conventional Zeeman splitting.
Mag Lab researchers analyzing chemical composition of Gulf oil spill

Amy McKenna
ICR User Program Director

The Magnet Lab’s Fourier transform ion cyclotron resonance (FT-ICR) team is playing a role in Deepwater Horizon oil spill clean up through a $198,790 Rapid Response Grant from the National Science Foundation. Working with the Woods Hole Oceanographic Institute, the team will map the chemical composition of the spilled oil as it travels and changes. The Mag Lab team, already recognized as the world leader in petroleum analysis, recently added Chang “Sam” Hsu, who has more than 30 years of experience in crude-oil analysis and was heavily involved in analytical method development used to characterize the Exxon Valdez oil spill. This article explains how the FT-ICR technique is ideally suited for this kind of study.

Oil companies essentially sell molecules, and every molecule has a mass. The first step in analysis of the BP Deepwater Horizon oil spill is the most difficult: resolving and identifying (at the chemical formula level, $C_xH_yN_zO_wS_v$) the tens of thousands of chemical constituents in the oil. Fortunately, FT-ICR mass spectrometry offers by far the highest resolving power of any mass analyzer (Figure 11), and thus the most detailed chemical fingerprint of crude oil and asphaltenes (Figure 8). The FT-ICR mass spectrometers (FT-ICR MS) at the Magnet Lab (Figure 1) can measure mass to better than 100 ppb (Figure 2), allowing researchers to assign a unique elemental composition to each kind of molecule. Moreover, because each additional ring or double bond in a molecule reduces its number of hydrogen atoms by two, we can determine the double bond equivalents (DBE = number of rings plus double bonds to carbon; a measure of aromaticity) for each molecule.

We then sort the thousands of chemical formulas according to the number of “heteroatoms” (N, O, and S) to generate heteroatom “classes.” Finally, we generate graphical images (e.g., isoabundance-contoured plots of DBE vs. number of carbons for each heteroatom class). Such images also facilitate comparisons between, e.g., raw crude
Figure 3. Completed pilot study of crude oil water-soluble polar species identified ~3600 water-soluble acidic (left) and basic (right) species identified in South American crude oil. A similar study of the BP oil will identify those oil species that have dissolved into the Gulf waters and the species that remain in the plumes.

Figure 4. Here, acidic species (that would require derivatization in GC analysis) are characterized systems by addition of agents such as tetramethylammonium hydroxide (TMAH), a strong, organic base soluble in organic solvents. More than 30,000 acidic species are successfully identified at a mass resolving power of 1 million at m/z = 400. Biotic and abiotic modification of the BP oil will increase the amount of these species and pose significant problems for conventional analytical techniques.

Oil vs. oil “weathered” for various periods. Simple modification of the ion source facilitates detailed compositional analysis of acidic, basic (+/- electrospray ionization, ESI) and nonpolar (atmospheric pressure photoionization, APPI) species in the crude. Polar compounds challenge routine analytical techniques, such as gas chromatography, but provide a unique opportunity for selective ionization of acidic (negative ESI) or basic (positive ESI) fractions coupled to ultra-high-resolution mass spectrometry.

In this way, we are generating a petroleome database available to all other researchers who are applying other analytical techniques (spectroscopy, rheology, titrations, etc.) that provide complementary information but are limited to the bulk sample (i.e., can’t resolve chemically different components). We coined the term “petroleomics” a few years ago: namely, the idea that it should be possible to correlate (and ultimately predict) the properties and behavior of petroleum and its products from sufficiently detailed knowledge of their chemical compositions.

Once we have a full “fingerprint” for the BP spill, it will be possible to analyze a particular contamination site to determine if the oil indeed came from that spill.

**EVOLUTION OF THE BP OIL SPILL**

An oil spill changes its chemical composition continuously, due to evaporation and dissolution. Thus, it is important to characterize those changes to best address their effects. We have previously applied FT-ICR MS to characterize the “weathering”
of automobile fuel and jet fuel. In those cases, the weathering was simple evaporation. For the BP spill, we can determine which components are lost or chemically modified during evaporation, contact with seawater, biodegradation and/or following any of various remediation treatments. For example, we have determined that up to \( \frac{1}{4} \) of the components of crude oil can dissolve in sea or fresh water (and which ones they are, Figure 3) — a convincing pilot demonstration of what will need to be done for the BP spill.

Biotic and abiotic modifications to the crude oil increase the relative abundance of polar species, ideal for high-resolution mass spectral characterization but problematic for GC separation approaches that require chemical derivatization prior to analysis. Furthermore, the increase in polar species, accompanied by the increase in compositional complexity via degradation products, severely limits the application of conventional analytical techniques, but has been successfully addressed with ESI FT-ICR MS, by modification of ESI solvent systems that access a wider range of chemical classes in crude oil (Figure 4). Weathering of the hydrocarbon matrix will also increase the polarity of components of the oil spill, further hindering characterization by GC techniques. FT-ICR MS characterizes polar and heavy oil fractions outside of the analytical window of most techniques without derivatization or sample fractionation.

**ANALYSIS OF LOW-VOLATILITY COMPONENTS**

In a refinery, crude oil is heated in stages to generate a series of products of increasing boiling point: naphtha, gasoline, kerosene, diesel, lube oil, etc. Similarly, the most volatile components of an oil spill will be lost quickly to evaporation. The persistent damage comes from the non-distillable species that include asphaltenes, known to the public as tar balls (Figure 5).

We have very recently provided strong evidence that those molecules are not large polymers (as might be expected from their high boiling point), but rather are multimeric aggregates of highly aromatic molecules averaging less than 1,000 Da in molecular weight.

Moreover, those aggregates can trap other species that would otherwise disperse from the spill. Finally, certain components of crude oil can accumulate to form deposits—we have recently been able to detect and identify the active substances before the deposit forms, thereby enabling preventative treatment. The ICR team is continuing to characterize oil:water emulsions in general and asphaltenes in particular. The increased complexity associated with nonvolatile fractions such as asphaltenes requires ultra-high resolution mass spectrometry to characterize the molecules that compose tar balls and can be used...
Figure 6.
Nonvolatile crude oil components (tar balls or tar mats) are extremely complex: the spectral segment at left shows the more than 240 mass spectral peaks across a 450 mDa window (the current world record) obtained with our 9.4 tesla FT-ICR instrument at a mass resolving power of more than 1.3 million at m/z = 500.

Figure 7.
Comparison of the vastly increased spectral complexity associated with nondistillable (asphaltene) fractions. Note the 10- to 15-fold increase in the number of peaks within a 1 Da window for the asphaltene fraction relative to the parent crude.
to characterize spilled oil in the Gulf of Mexico (Figures 6, 7). FT-ICR MS is the only technique that can provide molecular-level insight into the acidic, basic, and nonpolar species that self-associate and cause deposition (i.e., tar balls).

FT-ICR MS characterization of distillable and nondistillables fractions of whole crude oil reveals differences in heteroatom content and structure across a similar molecular weight distribution (Figure 8). Both fractions cover a similar carbon number range, but nondistillable species are shifted up in aromaticity and therefore have higher DBE values relative to distillable species. Similar comparisons among the maltene and asphaltene fractions isolated from the Deepwater Horizon crude and associated tar balls and mats will provide further insight into the nature of the most recalcitrant components. Here, we present data from the S2 heteroatom class but similar compositional trends were observed across all heteroatom classes.

**METAL-COMPOUND CHARACTERIZATION**

Characterization of metal-containing compounds is important for refineries because even at concentrations <1%, they can significantly impact refinery processes. However, they also reside in the least volatile fraction of crude oil and therefore concentrate in the nondistillables fraction (tar balls and asphaltenes). The concentration ratio of the two main petroporphyrins, deoxophylloerythroetioporphyrin (DPEP) and etioporphyrin (etio) that form vanadyl (VO) and nickel complexes serves as an oil maturity indicator (Figure 9): higher DPEP indicates a more mature crude oil and the ratio of nickel to vanadyl porphyrins decreases as a crude matures.

We have characterized the structural and compositional differences between petroporphyrins from whole crude and asphaltene fractions and are characterizing these compounds in Deepwater Horizon samples. Due to their low volatility and recalcitrance, metal-containing petroporphyrins concentrate in heavy ends and nondistillable fractions and may provide additional biomarker information. Figure 10 shows the double bond equivalents for vanadyl porphyrins from an asphaltene sample. Protonated ions have half-integer DBE values (DBE = c – h/2 + n/2 +1, calculated from the elemental composition, $C_hN_nV_vO_oS_s$), and may thus be distinguished from radical cations with integer DBE values. The most abundant class corresponds to vanadyl porphyrins with a deoxophylloerythroetioporphyrin (DPEP, $C_{3n}H_{2n-30}N_4V_1O_1$) structure. Assignment of elemental compositions can be used to calculate the degree and type of substitution of the petroporphyrin core structure.

**HOW ARE SAMPLES COLLECTED?**

Crude oil samples from the reservoir and crude after expulsion are now being characterized at the lab and a database of the chemical
constituents of the oil spill is being generated.

Untainted Gulf of Mexico water samples have been collected through the Florida State University and are currently in inventory at the Magnet Lab for future experiments. Samples will be collected through collaboration with Woods Hole Oceanographic Institute. Christopher M. Reddy, director of the Coastal Ocean Institute, has been funded through a RAPID proposal to collect surface and subsurface oil samples and tar balls from the BP spill and will provide samples for FT-ICR MS characterization. Collaboration will include comparison between GCxGC analyses conducted at Woods Hole and FT-ICR MS at the Mag Lab. Past collaboration between the two facilities has been used to characterize asphaltenes in oil reservoirs.

The standard classification (based on solubility and chromatography) of crude oil components (saturates/aromatics/resins/asphaltenes) does not reliably or completely separate different chemical classes. The chemical constituents of crude oil produce isobaric overlaps that must be resolved to identify crude oil species correctly (see Figure 1).
The 900 MHz ultra-wide-bore (UWB) magnet facility completed its fifth successful year of operation this summer, enabling research ranging from materials science to biology and proving that the 900 UWB — the first nuclear magnetic resonance (NMR) magnet built by Mag Lab engineers — is an engine for scientific discovery.

Including the initial year commissioning phase, the magnet has now been at field continuously for six years and still holds the record for bore size (105 mm) at its field strength. Together with a commercial NMR console and a fleet of probes developed at the Magnet Lab, the magnet has become a world-leading user facility, enabling studies that can’t be carried out elsewhere. It is in use by scientists nearly 365 days each year, with very little downtime for maintenance — quite an accomplishment for a magnet that almost didn’t happen.

Problems with the cryostat led to delays and concerns that the magnet would never come to field, but in the end, the Magnet Science and Technology Department came together to save the project, delivering a reliable system that performs very well for our users and is easy to maintain. Even a small defect hasn’t diminished the success of the 900 MHz. This small defect, found early in testing, causes the magnet to drift continuously at 0.6 ppm/hr, a potentially crippling problem for NMR with its ultra-narrow spectral lines. Because this drift is nearly constant and because of the wide bore, it is possible to compensate almost perfectly for the drift without distorting the homogeneity of the magnet. The drift has not limited the science that can be done on the 900 UWB.

MATERIALS RESEARCH

NMR of solid materials relies on “magic angle spinning” (MAS) of the sample in a miniature turbine to achieve spectral resolution. In liquids, rapid tumbling of the molecules averages out the magnetic dipolar coupling between nuclei. It is possible to approximate this effect by rapid spinning about the “magic” angle of 54.7°, allowing chemical resolution in solid samples. The ultra-wide bore of the 900 system provides room for the turbine to be placed within a small cryostat, providing these studies over a wide range of temperatures. A system of this type has been developed for the 900 UWB. Users now benefit from reliable and stable spinning operation from room temperature down to -150° C. Modifications to a commercial air bearing module, or stator, were carried out to reduce back pressure of the cold N₂ gas to suppress the formation of liquid droplets at the low temperature. Cold gas fittings were replaced with insulated versions to avoid ice build up. A
liquid nitrogen to gas heat exchanger cryostat was modified to allow for automatic refilling, providing continuous operation with minimal temperature fluctuations.

The variable temperature MAS probe was developed at the Magnet Lab to produce uniform RF magnetic fields of high amplitude over the spinning sample. It employs a transmission line matching network to allow for the high voltages needed to produce strong RF magnetic fields. Wavelength effects can significantly change the shape of the RF field over the sample at 900 MHz, so the VT-MAS probe includes a coaxial "bal-un" transformer around the matching network. The coaxial balun symmetrizes the coil current around the coil’s midpoint, greatly improving the uniformity of the RF field over the sample. A screw-in capacitor wand allows for quick changes of detection nucleus in a range from $^{47}$Ti (51 MHz) to $^{31}$P (364 MHz) without soldering.

Some of the first studies conducted in the 900 UWB with the variable temperature MAS probe led to exciting—and surprising—findings. The hydrogen-bonded compound NH$_4$H$_2$AsO$_4$ (ADA) has an antiferroelectric phase transition near 216 K. It’s also possible to induce the transition by substituting K for the NH$_4^+$ ion, so a study was undertaken to use $^{15}$N spectroscopy to examine the role of NH$_4^+$ in the transition. Investigators Riqiang Fu, Naresh Dalal and student Ozge Gunaydin-Sen expected improved sensitivity and resolution at 900 MHz compared to their preliminary measurements at 300 and 600 MHz. But they were surprised to find the resolution enhancement was even greater than the linear dependence predicted by simple theory. The greater-than-expected $^{15}$N spectral resolution led to a larger improvement in sensitivity than the expected $B_0^{3/2}$ (Figure 1). They attribute this “supra-linear” spectral resolution enhancement to an unexpected increase in the spin–spin relaxation time, T2. With the improved sensitivity and resolution, Dalal and Fu can now use the 900 UWB to probe the nature of the para-electric-antiferroelectric phase transitions in ADA to a depth not possible at lower fields. They have extended their study to identify and probe the dynamics of pretransitional clusters.

Crystalline RbH$_2$PO$_4$ (RDP), a solid acid of interest for fuel cell development, also exhibits a paraelectric-antiferroelectric phase transition,
but at a somewhat lower phase transition temperature. This transition now has been characterized with the accurate temperature control system on the 900 UWB to be 148.2±0.2 K. Currently, the high precision temperature control extends to approximately 120 K, therefore it was possible to characterize precisely the material both immediately above and below the phase transition with previously unavailable temperature control. Dalal and Fu found that, below the phase transition, one of the 31P resonances is almost independent of temperature, while the other has a substantial temperature dependence (see Figure 2). This unusual spectral behavior had not been observed at lower fields. Their observation was made possible by not only the enhanced temperature control, but also the excellent spectral resolution achieved in the UWB 900 — a mere 0.24 ppm for 31P. Further investigation is ongoing to discover the origin of this phenomenon, which could be a high field effect.

Hans Jacobson from the University of Aarhus, working with Zhehong Gan at the Magnet Lab, has used the 900 UWB to obtain high resolution 17O spectra of Cs2WO4, an industrial catalyst. Full characterization of quadrupolar and chemical shift tensors requires data obtained at a range of field strengths. The data from the 900 UWB, shown in Figure 3, provide the essential high field results necessary to generate a high resolution characterization of the tensors. Such characterizations are an important step toward understanding catalytic mechanisms. For 17O, a quadrupolar nucleus, the need for the very high field has been crucial. Here, the data permits the precise characterization of the quadrupolar and chemical shift tensors for all four oxygens showing that there is a dramatic difference in the asymmetry of the quadrupolar (ηQ ranges from 0.42 to 0.97) and chemical shift tensors (ηQ ranges from 0.03 to 0.48). Low temperature was used to suppress the jump motions of the oxygens between sites in the catalyst. Now that the high resolution tensors have been characterized to high resolution, the research will move on to a description of the dynamics for these oxygens as a function of temperature.

**BIOLOGICAL SOLID STATE NMR**

Membrane proteins can be exquisitely sensitive to their surroundings. To get a biologically meaningful structure from such a protein, it is necessary to analyze it within a native-like membrane environment. The aligned lipid bilayer sample preparation used in solid state NMR spectroscopy is the most native-like membrane protein environment used by any of the known structural methodologies, and this preparation has allowed solid state NMR to develop over the past decade into a pre-eminent tool for the characterization of membrane protein structures. Such samples are quite large, placing considerable demands on the NMR probe. Not only is high power necessary, but so is high RF homogeneity and minimal RF heating. This latter challenge is particularly important as the NMR frequencies approach that of a microwave oven. Heating samples by as much as 30°C was simply...
destroying these biological samples. Freezing samples is also destructive to the functionality associated with the dynamics of these proteins. And after all, it is understanding the functionality and mechanisms by which these proteins work that is the primary driving force for this field of science. The development of low-E probes by the Magnet Lab's Peter Gor'kov and Bill Brey has revolutionized membrane protein NMR spectroscopy. Rather than matching a single coil to two frequency channels by means of an external network, these probes use two separate coils, each optimized for its application. As shown in Figure 4, an inner solenoid provides high detection sensitivity through its excellent filling factor. An outer resonator, a single turn or loop-gap coil, is well-suited to produce the high frequency $^1\text{H}$ irradiation field. Using these probes, heating has been reduced by a factor of 15 without compromising other important aspects such as sensitivity and homogeneity. NMR spectroscopy on delicate membrane proteins was virtually impossible prior to the advent of these probes. Consequently, the combination of low-E probes and the large bore of this high field magnet resulted in a novel tool for membrane protein structural biology.

The first major structure to have been determined using the 900 UWB was a 20-kDa tetrameric M2 (22-62) protein complex from the Influenza A virus. The complex was surrounded by a near-native lipid bilayer to induce the most biologically appropriate structure. This was the Ph.D. dissertation work for Mukesh Sharma in Tim Cross's laboratory in the Department of Chemistry and Biochemistry at Florida State University. The molecular biology was overseen by Huajun Qin and the project represented a collaboration with David Busath and Emily Peterson at Brigham Young University in the Department of Physiology and Developmental Biology, and with Huan-Xiang Zhou, Myunggi Yi, and Hao Dong in Department of Physics at FSU. The structure of M2, which functions as a proton channel, has provided unique insights for the development of a detailed $^1\text{H}$ transport mechanism for this essential activity for the flu virus (Figure 5).

NMR research using quadrupolar nuclei is a major activity on the 900 UWB not only for materials science, but also for structural biology. In this later arena, research on the 900 UWB has advanced $^{17}\text{O}$ spectroscopy of biological macromolecules. Much of the chemistry conducted by biological systems occurs at the oxygen atoms, and yet for the past six decades, little $^{17}\text{O}$ spectroscopy has been possible because of the large quadrupolar interaction and the resultant second-order
broadening of the resonances. Consequently, NMR spectroscopic methods have focused on indirect probing of oxygen chemistry through the use of $^1$H, $^{13}$C and $^{15}$N as intermediaries. At high field, where the quadrupolar broadening of $^{17}$O is reduced and with sensitivity improvement that can be as dramatic as $B_0^4$, direct observation is possible for the first time. The wide-bore arguments outlined for membrane proteins apply here for the $^{17}$O spectroscopy of Gramicidin A, a cation selective channel produced by Bacillus brevis. Eduard Chekmenev, as a postdoc in the Cross lab, studied aligned samples in the 900 UWB to demonstrate that the $^{17}$O chemical shifts of the carbonyl oxygens that line the pore of this channel are very sensitive, not only to the binding of monovalent versus divalent cations, but also to exactly which monovalent cation is binding. As shown in Figure 6, the interactions between the channel and K$^+$, Na$^+$ Li$^+$ Cs$^+$ are readily distinguished. These results raise the possibility that the energetics of cation solvation in important cation channels, such as those associated with the conductance of nerve impulses, can be determined using high field $^{17}$O NMR.

**IMAGING**

The increased resonance frequency at 21.1 T over conventional field strengths combined with the size needed to accommodate large specimens (e.g. in vivo rodents or pathological specimens) makes the 900 UWB a unique and valuable resource for MRI-based research. Time-limited in vivo studies benefit from the increased sensitivity of the very high magnetic field, and ex vivo projects take advantage of field-dependent contrast to obtain unique scientific results. The sensitivity improvement obtained with the 900 UWB has been especially valuable for biologically important nuclei such as $^{23}$Na that are not sensitive enough for study at lower field. Because the 900 UWB magnet is one-of-a-kind, most RF equipment has been designed and constructed in-house. To meet the need for MRI user probes, Bill Brey and Peter Gor'kov, in collaboration with Barbara Beck and Dan Clark of the Magnet Lab’s Advanced Magnetic Resonance Imaging and Spectroscopy program at the University of Florida, have developed a modular system that meets the needs of in vivo applications but provides enough flexibility to satisfy a wide range of user samples.

The system consists of a stable probe frame that supports an animal chamber large enough to accommodate rats up to at least 350 g. This chamber is equipped with animal support, restraint and monitoring to provide users with the ability to maintain animals for prolonged experiments with minimal stress. Most critically, the modular probe has been designed so that RF coils are interchangeable and cover a range of frequencies and nuclei. Furthermore, the modular design has had a trickle-down effect, having been implemented at 600 MHz with plans to construct additional probes for other lower field platforms throughout the Magnet Lab.

One of the most successful RF coils to be
implemented is the sliding ring birdcage, which uses a movable end ring to achieve a uniform distributed impedance match (Chunqi Qian at NIH and Peter Gor’kov; Provisional Patent US 61264033). This design has been implemented in both single and double resonance configurations (Figure 7). Providing good isolation and sensitivity on both channels, the double resonance version allows users to obtain spatial co-registration of images from different nuclei, and provides the possibility for proton decoupling during acquisitions on low-{$\gamma$} nuclei, namely $^{23}$Na.

In addition to in-house RF efforts, the ultra-wide bore of the 900 provides an opportunity to develop gradient hardware to accommodate even larger sample sizes. Contracted through Resonance Research Inc., a specialized gradient set was constructed over a two-year period to provide the maximum possible diameter (64 mm) for imaging while also permitting for the highest possible gradient strength (1 T/m/A). Additionally, the gradient includes a dedicated $Z_0$ coil to provide $B_0$ compensation to correct minor main field fluctu-
ations induced by imaging gradients, a capability that was not previously available. This large-bore gradient set has proven to be remarkably robust and has become the workhorse of the MRI program on the 21.1-T magnet.

**IN VIVO PROTON MRI**

The potential of the 900 UWB as a tool for *in vivo* imaging and spectroscopy of rats was explored by Victor Schepkin and his colleagues, who compared its performance to the widely available pre-clinical field of 9.4 T—though it is notable that 9.4 T is currently the highest field available for human MR imaging. $^1$H images of the rat brain were optimized to illustrate anatomical detail using a time-efficient multi-slice gradient recalled echo experiment that achieved a 3D isotropic resolution of 100 µm (Figure 8). The SNR in the striatum of the rat brain was compared to equivalent studies made at 9.4 T to demonstrate a roughly linear increase in SNR (factor of 2), as expected for a relatively large animal for which sample losses dominate coil losses.
**IN VIVO SODIUM MRI**

The key biological role of sodium in physiology makes $^{23}$Na MRI a very sensitive and unique means of evaluating living tissue. As shown in Figure 9, *in vivo* sodium images can be achieved with high resolution (voxels of 0.125 µL) and with an acquisition time of 55 minutes. In this image of a mouse brain, the large variability in sodium intensity throughout the rodent brain is clearly evident. The most intense sodium signals can be seen in the ventricular cerebrospinal fluid (CSF), large blood vessels and eyes. *In vivo* sodium MR images of rodents provided a means of assessing sodium sensitivity gains between 21.1 and 9.4 T. Using the same acquisition parameters, the sodium SNR within the striatum of the rat brain was a factor of 3.3 greater on the 900 UWB, displaying that the quadrupolar nature of the $^{23}$Na nuclei provides a greater-than-linear dependence on field strength. Therefore, to obtain an equivalent SNR at 9.4 T would require more than 9 hours of acquisition.

These advancements are being used by numerous users to evaluate animal models of human disease. For example, migraines afflict around 30 million Americans and are typified by prolonged episodes of severe headache, nausea, cognitive impairment and discomfort from normal light, sound and odors. This manifestation belies an increased neuronal excitability. Using *in vivo*...
sodium MRI at 21.1 T, Dr. Michael Harrington of the Huntington Medical Research Institute and Eduard Chekmenev of Vanderbilt University detected previously unknown sodium increases of approximately 5% or more in the brain, intracranial CSF and vitreous humor of the eye in rats injected with nitroglycerine to induce a migraine (Figure 10). This study represents the first in vivo MRI detection of the functional changes in sodium during migraine, and one of the first functional studies in the brain to utilize sodium instead of blood oxygenation to monitor neurological pain. Moreover, these changes appear to be at least a factor of 2 greater than blood oxygenation changes typically seen in functional MRI.

HIGH FIELD NANOPARTICLE CONTRAST AGENTS

Contrast agents are an important part of both clinical and research MRI studies. Unfortunately, at higher fields, the effectiveness of commercial contrast agents based on either iron oxides or gadolinium compounds drastically decreases because of saturation levels that are reached below 1 T. The 900 UWB is motivating materials efforts to fabricate new contrast agents that will function effectively at higher field strengths. For example, paramagnetic dysprosium (Dy³⁺) has received attention because the magnetism of Dy complexes is impacted largely by Curie relaxation, which continually increases with field. In collaboration graduate student Joshua Kogot and Geoffrey Strouse of FSU Chemistry and Biochemistry, the Magnet Lab (graduate student Jens Rosenberg and Sam Grant of Chemical and Biomedical engineering) have investigated novel bimodal nanoparticles for use as contrast agents at high magnetic fields. The configuration of this high-field contrast agent incorporates a fluorescent quantum dot (QD) as a stable, bimodal platform for the delivery of intracellular MR contrast (Figure 11). A high payload of dysprosium (82 Dy³⁺) increases the MR contrast, yielding high r² relaxivity at least comparable to SPIOs and superior to Gd-based agents at clinical fields while providing fluorescent and MRI contrast in a single nanoparticle.

With regards to ex vivo investigations, MR microscopy is being explored as a useful imaging tool to phenotype mouse embryos. MRI provides complete volume coverage with a three-dimensional isotropic resolution. However, a main limitation for mouse embryo MR microscopy is signal-to-noise ratio (SNR). Also, large numbers of embryos are needed for phenotypic screening, making high throughput essential. Mark Henkelman at the Toronto Centre for Phenogenomics Mouse Imaging Centre overcomes such limitations at 7 T by scanning multiple embryos simultaneously to achieve the SNR to produce averaged atlases. The 900 UWB provided him the SNR to achieve higher resolution and contrast both inside and outside the central nervous system. In Figure 12, the mouse image was acquired at the highest resolution Henkelman has been able to achieve (16-μm isotropic), while also providing exquisite gray/white matter contrast and fine detail within the cardiovascular, hepatic and respiratory systems, which are normally less well defined and not as easily atlased at lower fields. These efforts are being combined with other imaging modalities (such as microCT) to provide quantifiable data about morphological alterations due to genetic manipulation, and were presented as part of a plenary lecture at 2010 ISMRM, Stockholm, Sweden.

Figure 13. 3D FLASH MRI partitions (TE/TR=12/50 ms, isotropic resolution=50 μm, acquisition time=4 hr) of a (a) healthy hippocampal section compared to (b) hippocampal sclerosis acquired at 21.1 T (900 MHz). Insets: magnified views of the hippocampus.
MRI-BASED HUMAN PATHOLOGY

Histopathology remains the gold standard for the evaluation of neurodegenerative disease in humans. Unfortunately, this definitive classification only can be performed postmortem in tissue specimen provided to histopathologists and neurologists. Though current clinical field strengths are not able to identify subtle alterations due to neurodegeneration, the high magnetic fields of the Magnet Lab provide the opportunity to identify and classify pathological specimens. As part of this effort, engineers at the Magnet Lab and the FAMU-FSU College of Engineering (graduate student Parastou Foroutan and Sam Grant) and clinicians at the Mayo Clinic Florida (Zbigniew Wszolek and Dennis Dickson) are collaborating on studies to image sections of the postmortem human brain to correlate MRI anatomy and quantification with histopathology. Utilizing the aforementioned modular probe and 64-mm gradient set, three-dimensional Fast Low Angle Shot (FLASH) scans (Figure 13) were acquired at the isotropic resolution of 50 μm over 4.3 hours at 14 °C. These datasets demonstrate significant morphological changes related to dementia in the sclerotic hippocampus. In collaboration with the Mayo Clinic, ongoing work is using the 900 UWB to help classify the severity and rank of different neurological diseases, such as Alzheimer’s and Parkinson’s disease, in order to improve pathological assessments and ultimately identify potential biomarkers that can be used clinically as early stage diagnostic indicators.

CONCLUSIONS AND FUTURE DIRECTIONS

The 900 UWB NMR system was and is a critical technological achievement for the Magnet Lab. As the first NMR system constructed by the lab, it has proven to be an unqualified success and, to date, has yet to be matched by industry in its unique combination of high magnetic field and bore size. The continuing efforts of the NMR and RF programs of the Magnet Lab have outfitted the 900 UWB with the enabling technology that permits users to make the most out of the myriad benefits afforded by the system. This process is ongoing with current efforts directed at further augmenting existing hardware developments. For example, two solid-state triple resonance probes are in development, one for aligned samples and the other for magic angle spinning. With respect to imaging, quadrature and phased array coils are being implemented to expand MRI capabilities on the 900 UWB. These efforts will enhance sensitivity while also reducing acquisition times for both in vivo and ex vivo experimentation. Furthermore, novel RF technology and approaches — such as dielectric resonators and far-field radiation — are being developed to extend the boundaries of current MRI techniques. In many of these efforts, the 900 UWB can serve as a staging system for future higher field systems, including the 36 T series connected hybrid magnet that will be available soon at the Magnet Lab.

Most critically, the 900 UWB has translated from a technological wonder to a powerful tool at the hands of the Magnet Lab user base for future scientific and engineering advancements.

Above: Mag Lab engineer Lee Marks sets up for a bucket test during developmental stages of the “900.”
Publications from the 900 UWB


17. Fu, R., (2009) Efficient Heteronuclear Dipolar...


Attending meetings and conferences is a vital and necessary career-development step for scientists in all disciplines, but such attendance can be financially and logistically burdensome for early career scientists struggling to balance this time-intensive part of their careers with the demands of family life. In fact, the cost of dependent care has been identified as a burden that impedes diversity in the scientific workforce, because it historically falls more heavily on women than men.

The Magnet Lab hopes to mitigate some of this strain with the implementation of a new dependent care travel grant program. Subject to the availability of funding, the Magnet Lab will soon offer small grants up to $800 per calendar year for qualified short-term, dependent-care expenses incurred by eligible recipients when traveling.

The term “early career scientist” includes undergraduate and graduate students, postdocs, and scientists with fewer than 10 years of active professional work since receiving a Ph.D. To be eligible, a scientist must be:

- An early career user traveling to a Magnet Lab facility in Tallahassee, Gainesville or Los Alamos to conduct an experiment as part of a user program (not including employees of Florida State University, the University of Florida or Los Alamos National Laboratory).

- A Magnet Lab early career scientist employed by any of the three Magnet Lab partner institutions who is invited to present papers at scientific meetings, conferences or workshops.

Awards may be used for either child or adult dependent care, or for extra dependent care at home while the grant recipient is traveling. The funds can also be used toward on-site care or transportation costs for either dependents or caregivers. The recipient will certify that the requested funds for dependent care are extra expenses due to the travel, and are above and beyond normal dependent care expenses (for example, day care or home nursing costs).

A dependent for purposes of this program is defined as 1) a child, newborn through 12 years of age (or any physically or mentally disabled child under the age of 18 who is unable to care for himself or herself), who resides with the applicant and for whom the applicant provides primary support, or 2) a disabled adult/elder (spouse, parent, parent-in-law, or grandparent) who spends at least eight hours per day in the applicant’s home and for whom the applicant has responsibility.

Eligible recipients must apply in advance of their travel using the Magnet Lab Dependent Care Travel Grant Program application. Applications will be due the first of January, March, May, July, September and November for travel during the following six months. A standing committee to review applications will be appointed by the Vice President for Research of Florida State University. Decisions will be made and candidates informed within two weeks of application.

Payment of these grants will be made post-travel through either the FSU Research Foundation or the FSU Foundation. Please note that this type of funding is considered taxable by the IRS, and will result in the issuance of an IRS Form 1099 to all recipients who receive awards in excess of $500.

For more information about this program, contact Dragana Popović at dragana@magnet.fsu.edu.
High-energy particle accelerators are some of the most expensive scientific equipment used to uncover the fundamental laws of nature. Indeed, the next 500 GeV–1 TeV proposed high energy accelerator project, the electron-positron International Linear Collider (ILC), is planned to be a 20- to 30-mile long tunnel, containing a chain of tens of thousands of soccer-ball-size resonator cavities made of pure Nb and cooled by superfluid He at 2K.

Over the years, the linear accelerators (LINACs) have become ubiquitous components of scientific and medical infrastructure, such as the spallation neutron source at Oak Ridge National Lab (ORNL), Continuous Electron Beam Accelerator Facility accelerator at the Jefferson Lab (JLab), and X-ray or THz free electron lasers, similar to the one that will be used in the Big Light source at the Magnet Lab (Figure 1).

As the size and the power of LINACs increase, they are facing the same power consumption problems as high-field DC magnets, forcing the users to move from Cu radio-frequency resonator cavities to superconducting (SRF) cavities made of pure Nb. The accelerating electromagnetic field is generated by SRF cavities in the Meissner state, for which RF dissipation is limited by the exponentially small surface resistance $R_s(T) \approx (\omega^2 / T) \exp(-\Delta / k_B T)$ where $\Delta$ is the superconducting gap proportional to the critical temperature $T_c$, and the resonance frequency $\omega \sim c / L \sim 1$–$2$ GHz $< \ll \Delta$ is inversely proportional to the cavity size $L$. As a result, SRF Nb cavities exhibit unprecedented quality factors $\sim 10^{10}$–$10^{11}$ at 2K, many orders of magnitude higher than what the best cavities built of normal metals can reach.

The power output of SRF cavities is limited by the peak RF magnetic field at the inner surface where vortices start penetrating into the cavity wall, causing its transition into the normal state. That’s why SRF cavities are made of Nb, which has the highest lower critical field $H_{c1} \approx 150$ mT among all superconductors. Moreover, $H_{c1}$ for Nb is not that different from the thermodynamic critical field $H_c \approx 200$ mT at which the density of Meissner screening currents flowing along the cavity surface reaches the depairing limit for the Cooper pairs. Recent technological breakthroughs achieved by several SRF groups worldwide have resulted in Nb cavities with breakdown magnetic fields close to the pairbreaking limit. Thus, a SRF cavity, which was originally designed as a tool to study high-energy physics, has unexpectedly become an ideal tool to study the fundamental non-equilibrium superconductivity at the maximum electromagnetic fields that can be sustained by the superconducting state.

The physics of pair-breaking processes, non-equilibrium kinetics of quasiparticles, and dynamics of vortices in superconductors under such extreme conditions at low temperatures has not been well understood, not least because of the lack of experimental means to apply such extreme electromagnetic power to a sample in a laboratory. The SRF cavities may provide such opportunities, enabling us to understand the
physics of the nonlinear surface impedance of a superconductor in very strong electromagnetic fields.

"As the size and the power of LINACs increase, they are facing the same power consumption problems as high-field DC magnets, forcing the users to move from Cu radio-frequency resonator cavities to superconducting (SRF) cavities made of pure Nb."

The achievement of the pair-breaking limit in Nb cavities poses the question: Are the best SRF cavities close to their intrinsic materials limit? The answer is far from obvious because, as far as the Meissner state is concerned, there are lots of superconductors with much higher $H_c$ and $T_c$ than Nb. However, all these materials have $H_{c1}$ much lower than $H_{c1,Nb}$ so the breakdown field is limited by penetration of vortices at rather low $H_{c1}$ values. It was recently suggested to resolve the problem of vortex penetration by coating inner surfaces of Nb cavities with multilayer nanostructures composed of superconducting and dielectric layers, the superconducting layers made of materials with $H_c$ and $T_c$ values higher than those for Nb (see Figure 2). If the thickness ($d$) of superconducting layers is much smaller than the London penetration depth, the parallel lower critical $H_{c1} = (2\phi_0/\pi d^2)\ln(d/\xi)$ can be greatly increased by reducing the layer thickness below ≈100 nm, thus delaying the field onset of vortex penetration to much higher values limited by $H_c$ of the coating material (here $\phi_0$ is the magnetic flux quantum, and $\xi$ is the coherence length). This idea offers an opportunity to overcome the intrinsic limits of the Nb technology by using many superconducting materials with higher $T_c$ and $H_c$ and the order parameter with no nodal lines so that $R_s \propto \exp(-\Delta/k_B T)$ remains exponentially small $T \ll T_c$ (this rules out d-wave superconductors such as high-$T_c$ cuprates and others). Multilayer coating would also make it possible to use the SRF cavities at 4.2K instead of 2K, resulting in huge savings in refrigeration costs for big LINACs. Currently groups in Japan, China and USA (Los Alamos National Lab, JLab, ORNL, Argonne National Lab) are working on practical implementations of the multilayer coating of Nb cavities. In particular, the group of M. Pellin at ANL is developing the Atomic Layer Deposition technique, which enables conformal coating of Nb cavities with multilayer nanostructures.

Understanding the SRF physics in thin films at strong fields can benefit from experimental and theoretical advances in other fields of condensed matter physics and materials science. For example, the technique developed by Irinel
Chiorescu’s group working on superconducting qubits for quantum computing was recently used to observe the nonlinear Meissner effect on dirty Nb films by measuring the frequency shift $\Delta f$ of a Nb thin film 20 GHz resonator strip line as a function of the parallel DC magnetic field. The use of films thinner than the London penetration depth has enabled us to significantly delay penetration of vortices, the major problem to reveal the nonlinear Meissner effect in previous experimental attempts. The five-fold enhancement of the vortex penetration field up to $\approx 1$T for a 65 nm dirty Nb film observed in Reference 2 is also a proof of principle for the thin film coating of SRF cavities. A theory based on the Usadel equations describes the experimental data very well. This method can have multiple applications. For example, measurements of the dependence of $\Delta f$ on the orientation of the DC magnetic field can reveal the symmetry of unconventional order parameters in new superconductors. Measurements of the field and temperature dependencies of $\Delta f$ can be used to obtain the surface impedance and the onset of vortex penetration for emerging SRF materials for thin film coating of Nb cavities and to study the nonlinear Meissner effect, which can contribute to the observed reduction of the quality $Q$ of Nb cavities at high rf fields.

This work was supported by NSF through NSF-DMR-0084173, DOE through PR # F9-297024, and by the state of Florida.

REFERENCES
NSF recognizes Mag Lab’s exemplary business systems

By Brian Fairhurst
Associate Director, Management and Administration

The National High Magnetic Field Laboratory is one of 22 National Science Foundation (NSF) Large Facilities. Typically, such a facility is multi-user with inherent risks because of the high dollar value, scientific complexity of the award activity and long-term commitment of support.

Because of the risk, the NSF recognizes the need to provide additional scrutiny of the business systems that affect stewardship of facility funds and developed the Business Systems Review (BSR) process to provide oversight of the people, processes and technologies that support the administrative management of a large facility.

A BSR is different than a NSF program review, focusing on the business activity that supports the daily administrative management of a large facility as opposed to the scientific activity.

The Large Facilities Office within the NSF’s Office of Budget, Finance and Award Management recently led the assessment of FSU/Mag Lab business systems by using desk reviews and site visits to determine whether the administrative systems used to manage the Mag Lab meet NSF expectations and comply with federal regulations. Eight core business systems were evaluated:

• General management
• Award management
• Budget and planning
• Financial management
• Financial reporting
• Human resources
• Procurement
• Property and equipment

During the review, subject matter experts from the NSF were matched with their counterparts of FSU and the Mag Lab. Key contributors to this effort from the Mag Lab and FSU were Judy McEachern, Roberta McManus, Damaris Cobb, Jim Payne, Clyde Rea, Renisha Gibbs, Julie Bickford, Marcie Doolittle, Bettina Roberson, Joel Miller, Bo Flynn and Brian Fairhurst.

The NSF identified just one review finding — although not required by FSU policies, the need to identify cost/price analysis for purchases greater than $6,000 — and several areas of best practices. Best practices are those areas that the NSF would like to share with other NSF organizations as representative of desired business systems:

• Creation of a Safety Awards Program: Exemplary individual performance in laboratory safety is acknowledged in small ceremonies during which staff are presented a plaque and small gift. Mag Lab management works with local community vendors to gather donated gifts. The program raises awareness and provides visibility to the lab’s commitment to safety.

• Incorporating safety tips and reminders into the slide-show presentations that run continuously on the laboratory flat panel display monitors in the lobby area.

• Implementation of a Cost Reduction Program: Created to identify cost-saving ideas and reduce expenses, this program recognizes cost saving practices for the laboratory, while reinforcing the importance of individual stewardship and fiscal responsibility.

• Commissioning of a study to forecast the economic impact of the laboratory on state and local economy. The study provided additional community visibility to the laboratory while emphasizing its significant role in the state and local community.

• Creation of comprehensive diversity webpages that include the lab’s diversity action plans, inclusion strategies, and information on the efforts undertaken by the Diversity Committee to target various diverse populations for outreach, hiring and retention. The content, format and style are user-friendly and showcase to the public the lab’s leadership support and commitment to diversity.

**SCOPE OF CONFERENCES**

**EP2DS** emphasizes the fundamental physics, including transport and optical properties of electronic states in low dimensional systems, which now include graphene, nanotubes and dielectric interfaces.

**MSS** addresses the synthesis, processing and applications of modulated materials, as well as novel systems, the broader range of carbon-based, hybrid, modulated organic, spintronic, and biologically based modulated structures.

**IMPORTANT DATES**

Online abstract submission open: **February 1, 2010**
Abstract submission deadline: **March 14, 2010**
Notification of acceptance: **April 25, 2010**
Conference hotel reservations Deadline: **May 25, 2010**
Early registration deadline: **June 18, 2011**

**TOPICS FOR EP2DS WILL INCLUDE:**

- Electronic, optical and magnetic properties of low-dimensional systems
- Semiconductor heterostructures, superlattices, quantum wires, and quantum dots
- Quantum Hall effects
- Physics of quantum information as applied to limited dimensional electronic states
- Spin phenomena in nanostructures
- Novel low-dimensional systems, including graphene, carbon nanotubes, and nanowires
- NEMS, biological and molecular structures
- Physics and devices for quantum information processing
- Organic semiconductors
- Hybrid structures
- Metal-insulator transitions
- Novel probes, experimental techniques

**TOPICS FOR MSS WILL INCLUDE:**

- Advances in growth and processing for modulated structures
- Nanowires and dots: electronic and optical properties
- Nanophotonic structures
- Spintronics and spin-effects in nanostructures
- Physics and devices for quantum information processing
- Heterostructures and superlattices
- Organic semiconductors and hybrid structures
- Novel modulated structures, including carbon nanotubes, graphene, molecular structures, NEMS, and bio-based structures
- Novel probing and fabrication techniques
HOW DO YOU THINK YOUR EXPERIENCE AT THE LAB HAS SHAPED YOUR SCIENTIFIC CAREER?

After years of using Electron Spin Resonance (ESR) for correlated electron systems, I came to the United States with the idea of learning a new experimental technique: Nuclear magnetic resonance in condensed matter physics. NMR has proven to be a powerful tool to study unconventional superconductivity and the experiments I've been pursuing in the field of heavy fermions and the novel iron arsenide superconductors are very much at the forefront of the field. The Magnet Lab has a fundamental role in this process since it provides not only great scientific environment and infrastructure, but also offers the unique possibility of performing experiments under extreme conditions. The research developed here as well as the experience acquired during this period will certainly distinguish me as a highly skilled scientist and help me to achieve my professional goals.

WHAT’S THE MOST IMPORTANT LESSON YOU’VE TAKEN AWAY FROM THIS PERIOD OF STUDY?

In experimental research there is no failed experiment. Every effort toward obtaining a new result, either positive or negative, certainly leads to an advance of our knowledge. My experience at the Magnet Lab has strengthened this “concept” even further.

DESCRIBE SOMEONE AT THE LAB WHOM YOU CONSIDER A MENTOR.

It is not easy to name a single person as a mentor when we speak about the condensed matter physics NMR group. My “mentors” at the Lab are a combination of three people: Arneil Reyes, Phil Kuhns and Bill Moulton. I was very much impressed and inspired by the skills shown by Arneil when making and putting all the pieces together while building the NMR probes. Yet Phil inspires me with his deep knowledge, not only of the NMR technique but also of the electronics responsible for its functioning. And Bill (the wise man), whose age still does not prevent him from coming to the lab every day. His passion and dedication for science fill me with excitement and encourage me to keep moving on. Research becomes more powerful when you transcend the personal, manage the abstract elements, and emphasize what is important. Working together with mentors in the field is a great way to get these concepts across.

WHAT MAKES THE MAGNET LAB SPECIAL?

The Magnet Lab is one of a kind not only in the United States but also worldwide. The list of several world records established since the lab opened attests for that and shows how strongly the Magnet Lab personnel are committed to success. Although the Magnet Lab is focused on providing a state-of-the-art user-oriented facility, which frequently receives scientists from around the world, it has managed to meet the perfect balance between serving the user community and developing an outstanding internal scientific program. In my opinion, this combination is the key to create an exciting environment for research.
THE MAGNET LAB’S
User Programs

The National High Magnetic Field Laboratory is a national resource that centralizes the country’s greatest magnet-related research tools, resources, and expertise. This approach is efficient and cost-effective, and encourages fruitful, collaborative research — across disciplines — at the highest level.

The Magnet Lab’s flagship magnets, designed and built in-house, are unrivaled anywhere in the world, and lab engineers are constantly striving to push fields higher still. But it’s not only the magnets that pull in upwards of 1,000 researchers each year; it’s also the world-class scientific support available at the Magnet Lab. The lab’s scientists and technicians develop the experimental instrumentation and techniques.

Interested in becoming a user?

Access to all Magnet Lab magnets is open to all scientists via a competitive proposal process. Go to www.magnet.fsu.edu and click on “Request Magnet Time” to get started!

The Magnet Lab is continually accepting proposals from interested potential users. Explore our user programs virtually at:

magnet.fsu.edu/userhub
Nuclear Magnetic Resonance

Instruments & Tools

NMR is the most versatile spectroscopic tool in science today. The Mag Lab's NMR program supports state-of-the-art facilities and unique capabilities that are available to users pursuing research in solution and solid state NMR, MRI and in vivo magnetic resonance spectroscopy.

The program has a mission to develop technology, methodology and applications at the highest magnetic fields through both in-house and external user activities.

The Magnet Lab also has a Condensed Matter NMR program that investigates, among other things, field-driven phenomena and phase transitions.

NMR Magnets

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<thead>
<tr>
<th>Field</th>
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<th>Capabilities</th>
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<td>900 MHz</td>
<td>105 mm</td>
<td>Imagery, Materials, Biosolids</td>
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<td>830 MHz</td>
<td>32 mm</td>
<td>Materials, low temperature</td>
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<td>600 #1 MHz</td>
<td>89 mm</td>
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<td>720 MHz</td>
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Scientists reviewing scans from the 900 MHz magnet.
The National High Magnetic Field Laboratory (NHMFL) seeks a visionary leader as the Chief Scientist in Chemistry and Biology. The successful candidate will have a broad understanding of the most important problems in chemistry, biology, biomedicine, and biomedical engineering.

The NHMFL is the world’s leading magnet laboratory, providing unique high-magnetic-field user facilities and hosting the research of approximately one thousand scientists annually. User research at the NHMFL spans condensed matter physics, materials research, chemistry, biology, biomedicine and biomedical engineering. The NHMFL consists of three campuses: Florida State University, the University of Florida and Los Alamos National Laboratory. It operates seven vibrant user programs: DC Magnetic Fields, Pulsed Magnetic Fields, High B/T (ultralow temperatures), Ion Cyclotron Resonance (ICR), Electron Magnetic Resonance (EMR), Nuclear Magnetic Resonance, and the Advanced Magnetic Resonance Imaging and Spectroscopy Center (AMRIS). Each of these seven user programs is well established with strong leadership and staff. Major existing instrumentation of particular interest to Chem/Bio includes (1) a 900 MHz ultra wide bore (105mm) instrument for MRI and NMR, (2) an 11 T/40 cm MRI instrument, (3) a 36 T hybrid magnet designed for 1.5 GHz NMR and 1000 GHz EMR (to be completed in 2012), and (4) a recently funded 21 T / 105mm ICR horizontal bore magnet for ICR applications.

The NHMFL is presently leading a world-wide advance in superconducting magnet technology. The NHMFL has exploited major advances in high temperature superconducting (HTS) materials over the last two years to demonstrate the feasibility of superconducting magnets that will exceed 30T. The NHMFL is making additional investments to realize high-homogeneity capabilities for HTS superconducting magnets. This represents a real revolution in magnet technology with the potential to transform Chem/Bio applications of high magnetic fields in ICR, EMR, NMR, and MRI.

Another major initiative under development at the NHMFL is the proposed construction of “Big Light”, a high-intensity light source that will provide bright, picosecond pulses of light that are tunable over the entire terahertz-to-infrared (THIR) frequency regime. This light source will be unique in the world and will be well matched to the energy and time scales relevant to much of the research conducted at the NHMFL. Consequently, high-field spectroscopy in the THIR regime represents another area with tremendous new opportunities for Chem/Bio research in the NHMFL user programs.

The NHMFL is looking for leadership to help broaden the operations and infrastructure funding base for the Chem/Bio user programs. The Chief Scientist in Chem/Bio will have a strong understanding of MRI, NMR, EMR, and ICR and will be an internationally recognized expert in at least one of these areas of technology. He/she will be expected to provide an expanded vision for the integrated use of existing and planned technologies to make a major impact in solving critical problems in chemistry & biology.

The successful candidate will have faculty appointments at both the University of Florida in Gainesville and Florida State University in Tallahassee. The primary institution and department are negotiable and will depend on the successful candidate’s particular area of major research emphasis.

Interested candidates should send a curriculum vitae, cover letter describing interests and experience, and names and contact information of three references to Prof. Arthur S. Edison (aedison@ufldu.edu), Chair, Chief Scientist in Chemistry and Biology Search Committee, National High Magnetic Field Laboratory. University of Florida and Florida State University are Equal Opportunity/Affirmative Action Employers.