NATIONAL HIGH
MAGNETIC
FIELD LABORATORY

NationalMagLab.org

FLORIDA STATE UNIVERSITY
UNIVERSITY OF FLORIDA
LOS ALAMOS NATIONAL LABORATORY

NSF

A HIGHER PEAK IS WAITING FOR YOU

Submit a proposal to experiment - FREE OF CHARGE - at the largest and highest-powered magnet laboratory in the world.

Perform experiments on our fleet of world-record magnets or work with our dedicated support scientists to conduct dozens of measurement techniques across condensed matter physics, materials research, magnet engineering, chemistry, biochemistry, geochemistry, bioengineering, and biology.

The only lab of its kind in the United States, the National High Magnetic Field Laboratory (National MagLab) is headquartered at Florida State University with branch campuses at the University of Florida and Los Alamos National Lab.

ON THE COVER

DC FIELD FACILITY

Turn to page 5 to learn more about the 41 T resistive magnet at the MagLab's DC Field Facility.

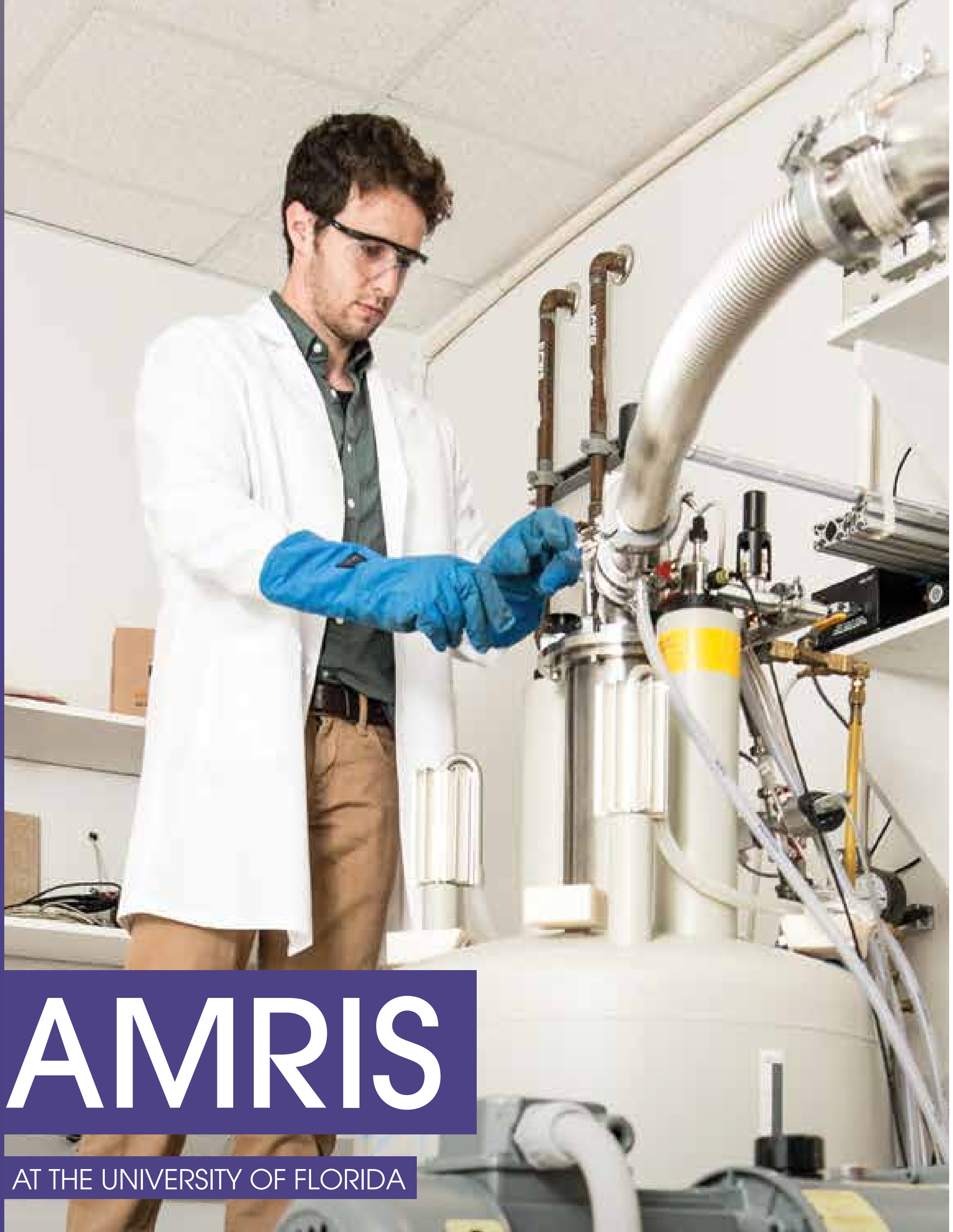
For a complete list of available instruments and techniques visit our webpage: NationalMagLab.org/user-facilities/dc-field

Seven distinct user facilities offer unique capabilities in high magnetic field research. Find the facility that elevates your research:

- **Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) Facility**
- **DC Field Facility**
- **Electron Magnetic Resonance (EMR) Facility**
- **High B/T Facility**
- **Ion Cyclotron Resonance (ICR) Facility**
- **Nuclear Magnetic Resonance/Magnetic Resonance Imaging (NMR/MRI) Facility**
- **Pulsed Field Facility**

We understand that there are times along your research journey that can feel like climbing a mountain, and our experienced support staff act as guides to help you reach new heights. As a user, you have access to experts in cryogenics, electronics, instrumentation, safety, machining/welding, and technical support to aid your work. We also offer financial support for first-time PI travel expenses or to cover short-term dependent care costs.

On our quest for ever-higher peak fields, the National MagLab's **Magnet Science & Technology group** and **Applied Superconductivity Center** work to find the materials and develop the technologies that lift your research to new pinnacles.



AMRIS

AT THE UNIVERSITY OF FLORIDA

Provides state-of-the-art instrumentation for high-resolution solution NMR, solid-state NMR, microimaging, animal imaging, and human imaging with eight spectrometer systems, including a 750 MHz wide bore, an 11 T/40 cm bore horizontal animal imaging magnet, and a 3 T human system. Unique capabilities include National MagLab constructed probes for preclinical imaging at 17.6 T, triple resonance MAS experiments at 750 MHz, HTS cryoprobes with unparalleled mass sensitivity and a variety of coils for in vivo imaging and spectroscopy.

UNIQUE CAPABILITIES

11.1 T, 40 cm bore
17.6 T, 89 mm bore
1.5 mm HTS cryoprobe
5 T, 1.2K DNP polarizer

Advanced Magnetic Resonance Imaging and Spectroscopy Facility

NMR Spectroscopy

NMR systems supporting spectroscopy of solution-state and solid-state samples are available from 500-800 MHz. Unique probes include a 1.5 mm, ^{13}C-optimized cryoprobe for mass-limited samples; a 10 mm ^{13}C, ^{31}P, ^{23}Na-optimized cryoprobe for perfusion and DNP studies; triple resonance Low-E MAS probes for biomolecular solid-state NMR applications; and a probe with gradients strengths up to 30 T/m for diffusion measurements in novel materials.

Imaging and MRI/S

Capabilities for imaging and diffusion measurements, on materials, in vitro cells, ex vivo tissue samples, and live animals, include MRI/S hardware for several nuclei (^{1}H, ^{13}C, ^{31}P) to characterize small animal biology; dissolution DNP for metabolic flux measurements and imaging metabolites; and microcoils coupled to strong planar gradients for imaging down to 10 µm resolution. Experiments are supported on horizontal bore 4.7 and 11.1 T systems as well as vertical bore 14.1 and 17.6 T systems.

DNP

A custom-built dissolution DNP polarizer is operating at 5 T/140 GHz/1.2 K. A range of RF inserts offer multinuclear capabilities for solid state studies of polarization dynamics and support in-vivo metabolic studies via MRI/S on 4.7 and 11.1 T scanners. A 3.35 T/95 GHz/1.2 K Hypersense polarizer is available for metabolic flux measurements on a 600 MHz NMR system equipped with a 10 mm Cryoprobe and an 18 mm room temperature probe.

NMR Probes

The National MagLab supports an NMR probe development program with pioneering low electric-field (Low-E) probes for solid-state NMR applications featuring reduced sample heating, homogeneous B_1 fields, high S/N, and reproducible performance across samples with varying dielectric properties. Solution-state NMR cryoprobes, utilizing inductively-coupled, high-temperature superconducting coils, enable ground-breaking sensitivity for ^{13}C detected NMR measurements using 30 µl sample volumes.

MRI Coils

Coils, ranging from 50 µm ID for excised tissue imaging to a 79 mm ID for rat whole body imaging, are integrated with gradients of up to 1.5 T/m for routine applications. The probes come with modular animal cradles and support features, such as heated water lines, anesthesia, and physiology monitoring, to ensure the well-being of the animals during imaging and to enable accurate and reproducible positioning. Coils ranging from 50-500 µm in size can be configured with a perfusion apparatus for imaging of live tissue slices. An annual RF coil workshop is offered to train users in building and testing RF coils tailored for specific frequencies and applications using the latest coil construction and testing methodologies, as well as designing and simulating their coils using CAD and electromagnetic simulation software.

HOW TO APPLY

Our magnets are open to all scientists — free of charge — via a competitive process, and we accept proposals throughout the year.

1. **Prepare documentation**
   A proposal and prior results report are required.
2. **Create a user profile on NationalMagLab.org/request-magnet-time**
   Returning users simply need to log in.
3. **Submit a request**
   Upload files and provide details about the proposed experiment.
4. **Report your results**
   By year's end, submit a report and information on publications resulting from your experiment.

Read the User Policies & Procedures for complete guidelines or contact the AMRIS Facility: **AMRIS-info@magnet.fsu.edu**

DC FIELD

AT FLORIDA STATE UNIVERSITY

The strongest magnetic fields in the world, coupled with state-of-the-art instrumentation and experimental expertise.

UNIQUE CAPABILITIES

Max. Field Range: **20–45 T**
Bore: **32-50 mm**
Temperature: **0.02–1000 K**
Current: **100 fA–10 kA**
Voltage: **10 nV–1 kV**
Pressure: **0–10 GPa**

DC Field Facility

The capability to move your research to new levels awaits you at a dedicated user facility that offers users the unparalleled combination of the strongest, quietest, DC magnetic fields in the world, coupled with state-of-the-art instrumentation and experimental expertise. The MagLab DC Field Facility contains 16 resistive magnet cells multiplexed to a stable, quiet, high-precision 56 MW DC power supply including the world record 45 T hybrid magnet, which offers scientists the strongest continuous magnetic field in the world, and the 25 T Split Helix magnet that provides unmatched optical access & fields. There are also several superconducting magnets that round out the lineup giving a wide range of magnet and sample environment combinations that enable research in high magnetic fields at temperatures from twenty millikelvin to a thousand kelvin.

Experimental Capabilities:

- Electrical Transport
- Surface Conductivity
- Heat Capacity
- Torque Magnetometry
- AC Susceptibility
- DC Susceptibility
- High Pressure
- Dielectric Measurements
- Microwave
- Dilatometry
- Surface Acoustic Wave Spectroscopy
- Resonant Ultrasound
- Pulse-Echo Ultrasound
- Raman Spectroscopy
- Ultra-Fast Magneto-Optics
- FIR Spectroscopy
- NMR
- EMR
- UV/Vis/NIR Magneto-Optics
- Ultra-Low Temperatures

DC Power System:

- 4 Power Supply Modules: 14 MW – 700 V @ 20 kA ea
- Active Filter for Ripple Reduction
  - Transistor Passbank
  - 10-100 PPM Ripple
- 28 MW (8000 ton) Chiller Capacity
- 56 MW Heat Exchange Capacity
- 16.3 M Liter Chilled H_2O Storage

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EMR

AT FLORIDA STATE UNIVERSITY

The EMR Facility provides unique instruments for Electron Magnetic Resonance studies of paramagnetic centers, magnetic molecules, and magnetic materials at very high magnetic fields and frequencies.

UNIQUE CAPABILITIES

Operating frequencies:
9 GHz – 1,000 GHz

Magnetic field range:
0 – 45 Tesla

Operating temperatures:
1.3 – 400 K

Applied pressure range:
0 – 25 kbar

CW & Pulsed EPR

Double Electron-Electron Resonance (DEER)

Electron Nuclear Double Resonance (ENDOR)

Single Crystal Rotation

Electrical Detection

Mössbauer Spectroscopy

Dynamic Nuclear Polarization

Electron Magnetic Resonance Facility

Anything with an unpaired electron

EMR stands for Electron Magnetic Resonance, which covers a variety of magnetic resonance techniques associated with the electron. The most popular of these techniques is Electron Paramagnetic/Spin Resonance (EPR/ESR), but also includes (Anti)Ferromagnetic Resonance (AFMR and FMR), as well as electron cyclotron resonance (CR). In simplified terms, EMR can be performed on any sample that has unpaired electron spins (or unfilled bands).

Applications across many disciplines

EMR has proven to be an indispensable tool in a large range of applications in physics, materials science, chemistry, and biology, including studies of impurity states, molecular clusters, antiferromagnetic, ferromagnetic and thin film compounds, natural or induced radicals, optically excited paramagnetic states, electron spin-based quantum information devices, transition-metal based catalysts; and for structural and dynamical studies of metallo-proteins, spin-labeled proteins, and other complex bio-molecules and their synthetic models.

Why high field?

High fields and frequencies provide high resolution, sensitivity, and access to high field phases in magnetic materials. They can address systems with large fine structure splittings, which occur in many compounds containing heavier elements such as transition metals, lanthanides, and actinides. EMR spectroscopy performed across a wide field range, and at multiple frequencies, allows users to independently constrain multiple interaction parameters that often define complex spin systems and structures.

Does your system contain iron?

The EMR program also provides access to Mössbauer spectroscopy at fields up to 8 T and temperatures down to 1.7 K for the study of frozen solution or solid state materials containing iron.

A large variety of techniques

A wide range of frequencies up to 1,000 GHz is accessible for continuous-wave spin resonance. Pulsed EPR is available at high power at 95 GHz and lower power up to 395 GHz. Single crystal rotation, ENDOR, and electrical detection are all possible. Contact us for your specific needs.

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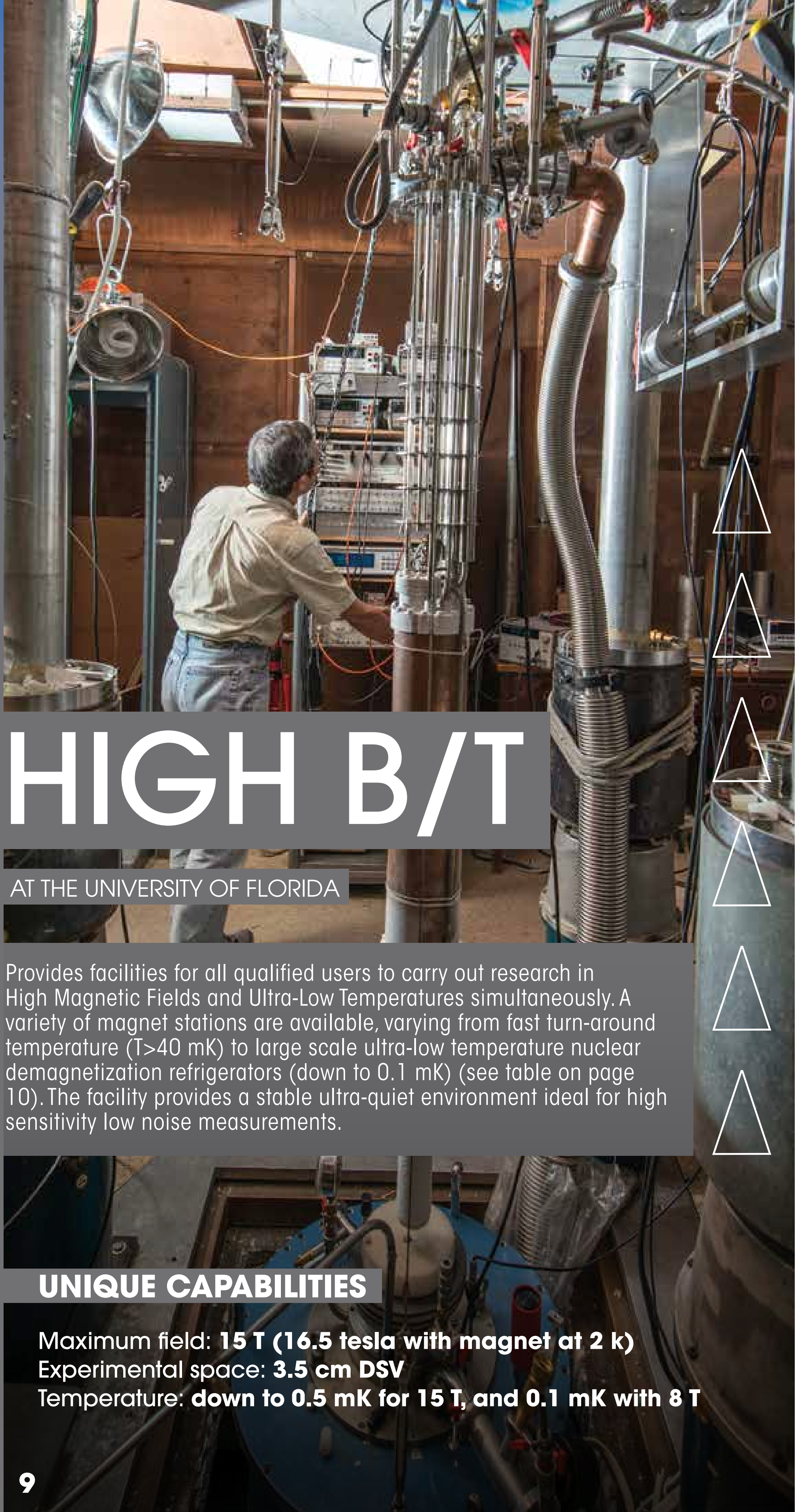

HIGH B/T

AT THE UNIVERSITY OF FLORIDA

Provides facilities for all qualified users to carry out research in High Magnetic Fields and Ultra-Low Temperatures simultaneously. A variety of magnet stations are available, varying from fast turn-around temperature (T>40 mK) to large scale ultra-low temperature nuclear demagnetization refrigerators (down to 0.1 mK) (see table on page 10). The facility provides a stable ultra-quiet environment ideal for high sensitivity low noise measurements.

UNIQUE CAPABILITIES

Maximum field: **15 T (16.5 tesla with magnet at 2 k)**
Experimental space: **3.5 cm DSV**
Temperature: **down to 0.5 mK for 15 T, and 0.1 mK with 8 T**

High B/T Facility

A suite of customized instrumentation and experimental set-ups is available. These include platforms for rotating samples at sub-mK temperatures, high sensitivity magnetic and dielectric susceptometry, transport studies, ultrasound measurements, and pulsed NMR spectrometers.

Refrigerator	Minimum Temperature	Maximum Field	Available Space
Nuclear, PrNi5	~0.5 mK	15 T	3.5 cm diameter
Nuclear, Cu	~0.1 mK	8 T	7.5 cm diameter
3He/4He Dilution	40 mK	10 T	3.5 cm diameter

A suite of customized instrumentation and experimental set-ups is available. These include platforms for rotating samples at sub-mK temperatures, high sensitivity magnetic and dielectric susceptometry, transport studies, ultrasound measurements, and pulsed NMR spectrometers.

Transport Measurements

Special sample cells that use sintered silver heat sinks immersed in liquid helium three to thermalize samples are available for transport measurements with thermal bath temperatures down to 0.5 mK. 2DES studies have been carried out with electron temperatures as low as 4 mK. Cells can be tilted relative to the magnetic field.

Magnetic and Electric Susceptibilities

AC susceptometers are available for measurements of magnetic and electric susceptibilities at ultra-low temperatures. The samples cells are totally immersed in a cell filled with liquid 3He. High sensitivity bridges are used to make the measurements. The systems have been used to measure magnetic susceptibilities of quantum magnets up to 15 T and below 0.5 mK.

NMR Probes/Spectrometers

Heterodyne and homodyne pulsed spectrometers are available for NMR and NQR studies of materials down to ultra-low temperatures for frequencies 1-1,000 MHz. Low temperature probe designs and cryogenic electronics enable ultra-high sensitivity. Continuous wave techniques available to reduce sample heating at sub-mK temperatures are useful for samples with very long relaxation times.

Ultrasound Measurements

For highly attenuating materials, transmission measurement is difficult to use. We offer an acoustic impedance measurement capability which is valuable in detecting transition signatures.

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ICR

AT FLORIDA STATE UNIVERSITY

The Ion Cyclotron Resonance facility provides the highest mass resolving power and accurate mass measurement for cutting-edge research that includes biomolecules (e.g., top-down proteomics, post-translational modifications, and hydrogen-deuterium exchange), informatics, nanocarbon materials, and environmental and petrochemical mixtures. The facility's four FT-ICR mass spectrometers feature high magnetic fields – including the world-record 21 tesla – and are compatible with multiple ionization and fragmentation techniques. The facility features staff scientists who support instrumentation, software, biological, petrochemical, and environmental applications, as well as a machinist, technician, and several rotating postdocs who are available to collaborate and/or assist with projects. Software platforms are designed in-house to meet specific applications.

UNIQUE CAPABILITIES

- 9.4, 14.5, and 21 Tesla
- Ionization Modes: ESI, APPI, APCI, LD, DART, AP/LIAD-CI
- Online liquid chromatography
- Fragmentation: CAD, IRMPD, UVPD, ExD

Ion Cyclotron Resonance Facility

The 21 T Hybrid FT-ICR Mass Spectrometer

The combination of high magnetic field and strict control of the number of trapped ions results in external calibration broadband mass accuracy of less than 100 ppb rms, and resolving power greater than 300,000 ($m/\Delta m_{50\%}$ at m/z 400) is achieved at greater than 1 mass spectrum per second. Novel ion storage optics and methodology increase the maximum number of trapped ions that can be delivered to and efficiently detected in the FT-ICR cell, thereby improving dynamic range for tandem mass spectrometry and complex mixture applications. C. L. Hendrickson, et. al., 21 Tesla Fourier Transform Ion Cyclotron Resonance Mass Spectrometer: A National Resource for Ultrahigh Resolution Mass Analysis, *Journal of the American Society for Mass Spectrometry*, 26, 1626-1632 (2015).

14.5 T Hybrid FT-ICR Mass Spectrometer

The 14.5 T instrument is configured identically to the 21 T instrument, and provides external calibration broadband mass accuracy of less than 300 ppb rms, and resolving power greater than 200,000 ($m/\Delta m_{50\%}$ at m/z 400) is achieved at greater than 1 mass spectrum per second. T. M. Schaub, et. al., High Performance Mass Spectrometry: Fourier Transform Ion Cyclotron Resonance at 14.5 Tesla *Analytical Chemistry*, 80, 3985-3990 (2008).

9.4 T Hybrid FT-ICR Mass Spectrometer

This custom-built instrument was redesigned to improve sensitivity and acquisition speed, and to provide an optimized platform for future instrumentation development. The instrument was designed around custom vacuum chambers for improved ion optical alignment, minimized distance from the external ion trap to magnetic field center, and high conductance for effective differential pumping. N. K. Kaiser, et. al., A novel 9.4 tesla FTICR mass spectrometer with improved sensitivity, mass resolution, and mass range, Journal of the American Society for Mass Spectrometry 22, 1343-1351 (2011)

9.4 T Actively Shielded FT-ICR Mass Spectrometer

This FT-ICR system is configured for laser desorption ionization in a variable pressure inert background gas. A versatile cluster source is available to study synthesis and self-assembly processes of novel encapsulated molecular nanocarbons and related materials (e.g., clusterfullerenes). A new source that incorporates two lasers has been developed to expand capabilities for chemical manipulation of cluster compounds and catalysis applications, as well as probe high-energy reactions that produce astrophysically relevant carbon-based complexes. This custom-built instrument was redesigned to improve sensitivity, acquisition speed, and include a variety of dissociation techniques for structural analysis.

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Read the User Policies & Procedures for complete guidelines or contact the ICR Facility: **ICR-info@magnet.fsu.edu**

NMR

AT FLORIDA STATE UNIVERSITY

The NMR facility provides a variety of NMR/MRI magnets and spectrometers, dynamic nuclear polarization instruments and custom made probes up to 1.5 GHz.

UNIQUE CAPABILITIES

36 T SCH magnet and 1.5 GHz NMR

900 MHz ultrawide bore

600 MHz MAS DNP

Low-E NMR probes

Nuclear Magnetic Resonance and Magnetic Resonance Imaging Facility

Instrument Overview

900 MHz, 105-mm bore magnet enables imaging and NMR spectroscopy of live animals up to 350 g. - Multinuclear ssNMR probes for both biomolecular solids and materials applications are available with 900, 830, 800, 600, 500 MHz NMR systems. Both oriented and MAS (1.3-7 mm rotors) sample configurations are supported. - Solution NMR systems supported with conventional and cryoprobes are available at 600 and 800 MHz. - A 600 MHz DNP NMR system with an AV-III HD console utilizing a 40-watt, 395 GHz gyrotron via a quasioptical table is now available for users with a 3.2 mm MAS probe operating down to 100 K and multinuclear capabilities for biomolecular and materials applications. The 14.1 T wide bore magnet has a sweep range of ±1,280 Gauss to enable studies with a wide range of radicals. - The National MagLab supports an NMR probe development program with pioneering Low-E probes for ss NMR applications featuring reduced sample heating, homogeneous B_1 fields, and increased S/N. Tune cards with X-Y circuit elements slide in and out of the probe head to enable switching to different X and Y isotopes.

MAS Probe

Low-E Probe

NMR At 1.5 GHz!

We are commissioning a 36 T hybrid superconducting /powered (series connected hybrid or SCH) magnet for NMR up to 1.5 GHz ^{1}H resonance frequency. The SCH facility's unique mission will be to perform potentially transformative science using magnetic resonance in applications, from biological macromolecules to synthetic catalysts using NMR and from battery materials to biological tissues using MRI. The system is equipped with a state-of-the-art Bruker ADVANCE NEO NMR/MRI console and custom made probes. Current probe capabilities include a single-resonance MAS probe (3.2 mm RevNMR rotor) for quadrupolar and low-g nuclei NMR, a ^{1}H-X for static and oriented biological samples, and a 2 mm HCN triple-resonance low-E MAS probe for bio-solids applications. All three probes have variable temperature capabilities and an external lock for field regulation. More probes and imaging capability are under development.

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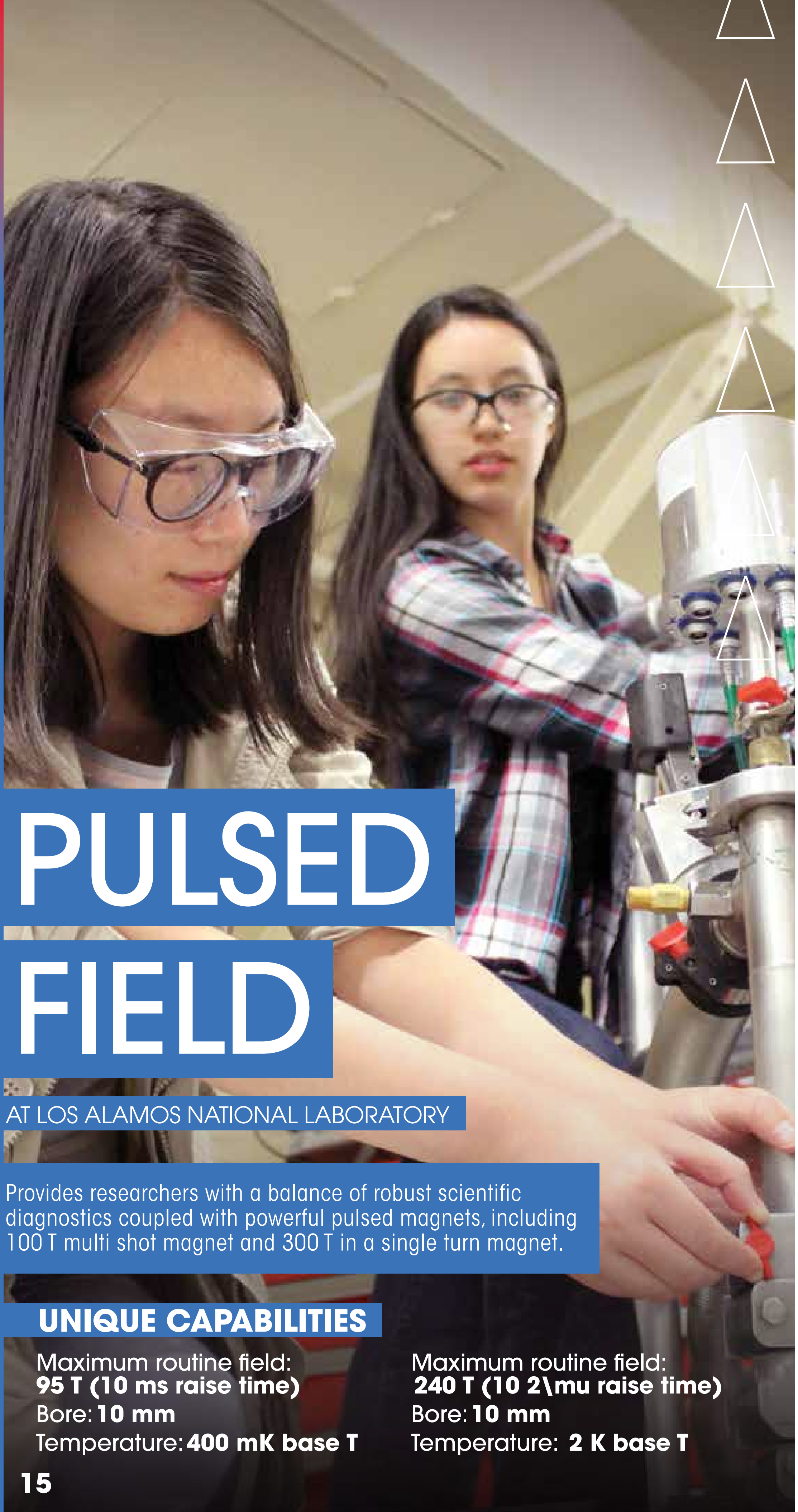


PULSED FIELD

AT LOS ALAMOS NATIONAL LABORATORY

Provides researchers with a balance of robust scientific diagnostics coupled with powerful pulsed magnets, including 100 T multi shot magnet and 300 T in a single turn magnet.

UNIQUE CAPABILITIES

Maximum routine field:
95 T (10 ms raise time)
Bore: **10 mm**
Temperature: **400 mK base T**

Maximum routine field:
240 T (10 2\mu raise time)
Bore: **10 mm**
Temperature: **2 K base T**

Pulsed Field Facility

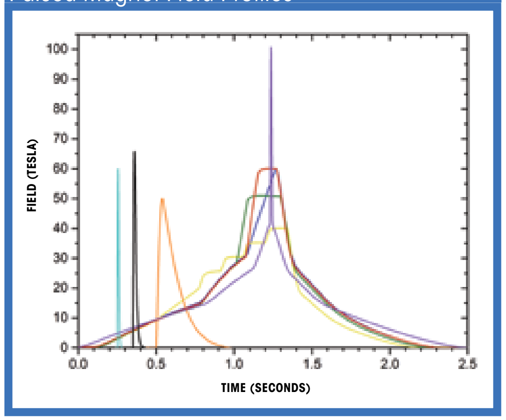
Overview

Scientific exploration of matter in extreme magnetic fields ($\mu_0 H > 45$ T) is only possible by utilizing pulsed magnets. The National MagLab - Pulsed Field Facility (PFF) is the only pulsed magnetic user facility in the US and is located at the Los Alamos National Laboratory in New Mexico. We are funded by the National Science Foundation and the Department of Energy and open to any qualified user from around the world. Our facility provides world leading experimental capabilities in extreme magnetic fields. We maintain many standard measurement techniques as well as develop custom instrumentation to address specific User's experimental needs. Our capabilities provide users with unprecedented insight into a wide range of materials physics challenges.

Our World Leading Pulsed Magnets

- Generator-driven and Multiplex
  60 T controlled waveform 32 mm Bore 100 msec
  100 T Multi-shot 10 mm Bore 25 msec
- Capacitor-bank Driven
  65 T Short Pulse 15 mm Bore 25 msec
  75 T 15 mm Bore 15 msec
  300 T Single Turn 10 mm Bore 6 µsec
- Including Superconducting Magnets
  18/20 T 52 mm Bore
  7 T Split Optics

Pulsed Magnet Field Profiles



Experimental Capabilities

- Electrical Conductivity, Resistivity, Hall Effect
- Heat Capacity
- RF Contactless Conductivity
- Pulse-Echo Ultrasound
- Cyclotron Resonance
- Pulsed IV and Jc
- Microwave Conductivity and Spectroscopy
- Electron Paramagnetic Resonance (EPR)
- Dilatometry, including Fiber Bragg
- Dielectric, Electric Polarization, and Multiferroic measurements
- Magnetometry, Compensated coil susceptometry, Extraction, and Torque
- Broadband absorption, reflection, and photoluminescence spectroscopy (300-1600 nm)
- Ultrafast pump-probe studies and time-domain THz spectroscopy (under development)
- Custom Measurement Development

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GUIDANCE FROM THE GROUND UP

OPPORTUNITIES FOR STUDENTS, POST-DOCS AND EARLY CAREER SCIENTISTS

The National MagLab supports the professional and career development of students and postdocs.

Research Experience for Undergrads (REU)

This summer internship lets undergraduates explore science at the extremes of magnetic fields, pressure, and temperature while working alongside some of the finest scientists, magnet designers, and engineers in the world.

MagLab User Summer School & Theory Winter School

These weeklong workshops help advanced graduate students, postdocs or early career theorists or experimentalists develop practical experience. User Summer School features hands-on tutorials on measurement techniques combined with practical exercises and expert talks to provide a full package of ways to broaden your skills. Theory Winter School offers lectures and poster presentations on subjects of continuing relevance in condensed matter and materials research theory. (available for Tallahassee facilities only).

Fellowships

FSU Physics Masters-to-PhD Bridge Program

This program helps talented students who lack preparation in some areas of undergraduate physics to transition into Florida State University's physics PhD program, or similar programs elsewhere in the United States. The program supports up to four Bridge Fellows each year. These fellows will initially be appointed as research interns at the National MagLab in the summer prior to enrollment in the physics graduate program.

The lab has two prestigious named fellowships - The **Crow Fellowship** and the **Dirac Fellowship** - which provide 2 year appointments for postdocs.

Connect with us on social media for updates and application information for these opportunities:
NationalMagLab

FUNDING RESOURCES FOR USERS

Scientists who share the results of their experiments use our facilities for free. In addition, the MagLab offers several funding opportunities to assist with dependent care, travel, and other expenses.

First-Time User Fund

MagLab facilities are generally available to users without cost. To encourage new research activities, first-time PIs may request modest support for travel expenses (available for Tallahassee facilities only).
$1,000 for international users; $500 for domestic users
Discuss your request with the applicable facility director. There is no deadline.

Dependent Care Travel Grant

Subject to the availability of funding, the MagLab offers small grants of up to $800 for qualified, short-term dependent care expenses.

Visiting Scientist Program

This program provides greater access to our facilities and seeds research programs that advance the laboratory. Funding is principally to support travel and local expenses. Requests for stipends are considered but given a lower priority.

Learn more about these programs:
nationalmaglab.org/user-resources/funding-opportunities