THESIS DEFENSE: Optically Detected Nuclear Magnetic Resonance Above and Far Below Earth's Magnetic Field

SVEN BODENSTEDT

February 15, 2024

15:00 to 16:00

Auditorium and Online (Teams)

This thesis describes theoretical background, simulations, experimental apparatus and measurements of nuclear spin dynamics via optically pumped magnetometers in unconventional magnetic field regimes. It is divided into four parts: Magnetometry, Nuclear Magnetic Resonance Spectroscopy, Nuclear Relaxation Dispersion, and Nuclear Spin Control, each looking at different aspects of this topic.

The magnetometry section describes how through integration of techniques from DC spin-exchange relaxation-free and rf magnetometers, a widely tunable magnetometer is developed that offers a nearly flat response from DC up to few kHz with a sensitivity of less than 20 fT ?Hz. Within this range, it surpasses the capabilities of inductive detection methods and eliminates the necessity for cryogenic temperatures that are required for

superconducting quantum interference devices (SQUIDs).
The subsequent part employs the magnetometer for conducting nuclear magnetic resonance spectroscopy experiments involving coupled nuclear spin systems. A comprehensive analysis is undertaken to ascertain the optimal magnetic field that yields the most precise determination of the J-coupling constant. It is shown that for some systems the ultra-low field regime offers advantages compared to the zero- and high-field regime.
A key factor in choosing the optimal field is the nuclear spin relaxation's strong field dependency, explored in the thesis's third part. This section thoroughly examines this subject in the unconventional ultra-low field range, discussing long-lived coherences and the impact of long correlations in molecular dynamics. The thesis experimentally investigates this by adapting the established fast-field cycling method to ultra-low fields and combining it with optical detection.
The thesis' s final part focuses on enhancing nuclear spin dynamics manipulation through advanced methods that ensure selective, efficient, accurate, and fault-tolerant spin control. Ultra-low fields possess unique attributes, making even basic techniques like spin-selective resonant pulses challenging to implement. To address this, novel concepts were devised, enabling effective spin control in the ultra-low field range, rivaling or surpassing high-field counterparts. The efficiency of these improved pulse sequences is demonstrated in dynamical decoupling, polarimetry, and spectral filtering experiments.

Thesis Director: Prof Dr. Morgan Mitchell and Dr. Michael Tayler
Hosted by: Prof. Dr. Morgan Mitchell