A 52: SYQM 2: Quantum limited measurement applications 2

Time: Friday 14:00–16:15 Location: V47.01

Invited Talk A 52.1 Fri 14:00 V47.01

Nanoscale magnetic resonance imaging: Progress and challenges — •Daniel Rugar — IBM Research Division, San Jose, California, USA

Magnetic resonance imaging (MRI), based on the sensitive detection of nuclear spins, enables three dimensional imaging without radiation damage. Conventional MRI techniques achieve spatial resolution that is at best a few micrometers due to sensitivity limitations of conventional inductive detection. The advent of ultrasensitive nanoscale magnetic sensing opens the possibility of extending MRI to the nanometer scale. If this can be pushed far enough, one can envision taking 3D images of individual biomolecules and, perhaps, even solving molecular structures of proteins. In this talk we will discuss issues related to nanoscale magnetic resonance imaging, especially its implementation using magnetic resonance force microscopy (MRFM). MRFM is based on the detection of ultrasmall (attonewton) magnetic forces. While 3D spatial resolution below 5 nm has been demonstrated, further progress depends on overcoming poorly understood near-surface force noise effects. We will also consider the future possibility of using NV centers in diamond for detection of nanoMRI.

Invited Talk A 52.2 Fri 14:30 V47.01

Optical Far-Field Addressing of Single Spins Beyond the Diffraction Limit at Enhanced Collection Efficency — •Dominik Wildanger[1], Jero Maze[2], Benno Koberstein-Schwarz[1], Jan Meijer[3], Sébastien Pezzagna[3], Brian Patton[4], Jason Smith[4], and Stefan Hell[1] — [1]MPI for Biophysical Chemistry, Göttingen, GER — [2]PUC, Santiago, Chile — [3]Ruhr-Universität, Bochum, GER — [4]University of Oxford, Oxford, UK

The electron spin associated with charged nitrogen-vacancy (NV) centres in diamond is optically addressable, because it can be polarised via an optical excitation, while its spin information is encoded in its fluorescence signal and can be read-out by using a fluorescence microscope. Till recently fluorescence microscopy was limited by diffraction and thus the spins of close-by NV- centres could not be addressed individually. Today techniques are available to fundamentally overcome the diffraction limit in fluorescence microscopy and some of them could be successfully applied on the NV- centre.

Here we show how to address single electron spins in diamond with single digit nanometre resolution by combining STED (Stimulated Emission Depletion) with ODMR (Optically Detectable Magnetic Resonance) techniques. Furthermore we overcome the limitations on fluorescence efficiency and focus quality caused by the high index of refraction of diamond by employing a solid immersion lens (SIL). We demonstrate that SIL enhanced STED-ODMR provides a spin addressing resolution potential of 1.6 nm. Concurrently the collection efficiency is increased by a factor of 5.

A 52.3 Fri 15:00 V47.01

Beating the classical resolution limit via multi-photon interferences of independent light sources — Steffen Oppel[1], Thomas Büttner[1], Pieter Kok[2], and •Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Department of Physics and Astronomy, University of Shefield, Shefield, UK

Multi-photon interferences with indistinguishable photons from independent light sources are at the focus of current research due to their potential in optical quantum computing, creating remote entanglement and quantum metrology. The paradigmatic states for multi-photon interference are the highly entangled NOON states which can be used to achieve enhanced resolution in interferometry and lithography [1]. Multi-photon interferences from independent, uncorrelated emitters can also lead to enhanced resolution [2]. So far, such quantum interferences have been observed with maximally two emitters. Here, we report multi-photon interferences with up to five independent emitters, displaying interference patterns equivalent to those of NOON states. Experimental results with independent thermal light sources confirm this NOON-like modulation. The experiment is an extension of the landmark measurement by Hanbury Brown and Twiss who investigated intensity correlations of second order. Here we go beyond this level by measuring spatial intensity correlations up to fifth order to further increase the resolution.

[1] A. N. Boto et al., Phys. Rev. Lett. 85, 2733 (2000).
[2] C. Thiel et al., Phys. Rev. Lett. 99, 133603 (2007).

A 52.4 Fri 15:15 V47.01

High Dynamic Range Magnetometry with a Single Nuclear Spin in Diamond — •Gerald Waldherr[1], Johannes Beck[1], Philipp Neumann[1], Ressa S. Said[2], Matthias Nitsche[1], Jason Twamley[3], Fedor Jelezko[4], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart — [2]Institut für Quanten-Informationsverarbeitung, Universität Ulm, 89081 Ulm — [3]Centre for Engineered Quantum Systems, Faculty of Science, Macquarie University, Sydney, Australia — [4]Institut für Quantenoptik, Universität Ulm, 89073 Ulm

Sensors based on the nitrogen-vacancy (NV) defect in diamond are being developed to measure weak magnetic and electric fields at nanoscale. However, such sensors rely on measurements of a shift in the Lamor frequency of the defect, so an accumulation of quantum phase causes the measurement signal to exhibit a periodic modulation. This means that the measurement time is either restricted to half of one oscillation period, which limits accuracy, or that the magnetic field range must be known in advance. Moreover, the precision increases only slowly, as $T^{-0.5}$, with the measurement time T. We implement a quantum phase estimation algorithm on a single nuclear spin in diamond to combine both high sensitivity and high dynamic range. By achieving a scaling of the precision with time to $T^{-0.85}$, we improve the sensitivity by a factor of 7.4, for an accessible field range of 16 mT, or alternatively, we improve the dynamic range by a factor of 130 for a sensitivity of 2.5 $\mu T/Hz^{0.5}$. These methods are applicable to a variety of field detection schemes, and do not require entanglement.

A 52.5 Fri 15:30 V47.01

Enhancement of a single electron spin based magnetometer by utilizing a small nuclear spin quantum register — •Philipp Neumann[1], Gerald Waldherr[1], Matthias Nitsche[1], Sebastian Zaiser[1], Fedor Jelezko[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Institut für Quantenoptik, Universität Ulm

The negatively charged nitrogen-vacancy (NV) center in diamond and its associated nuclear spins form a versatile small quantum register. Apart from its potential applications in quantum information processing the susceptibility of its quantum coherence to external stimuli like magnetic and electric fields render the NV center a tiny quantum sensor. Its high spatial confinement allows to build very small sensing devices which lead to a sample-probe distance of only a few nanometer potentially enabling the detection of single electron or even nuclear spins.

Here we show how a small quantum register of proximal nuclear spins around the NV center can be used to drastically increase the performance of the NV electron spin as a magnetic field sensor.

A 52.6 Fri 15:45 V47.01

Sub shot-noise interferometry from measurements of the one-body density — Jan Chwedenczuk[1,2], •Philipp Hyllus[1,3], Francesco Piazza[1,4], and Augusto Smerzi[1,5] — [1]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]Faculty of Physics, University of Warsaw, ul. Hôza 69, 00-681 Warsaw, Poland — [3]Department of Theoretical Physics, The University of the Basque Country, P.O. Box 644, E-48080 Bilbao, Spain — [4]Physik Department T34,Technische Universität München, James-Franck-Straße, 85747 Garching, Germany — [5]INO-CNR and LENS, 50125 Firenze, Italy

We show that a sub shot-noise sensitivity – associated with the quantum correlations present in the state entering the interferometer – can be achieved with particle-position measurements using a new phase estimator which does not require *any* knowledge about these correlations, and is based on the single-body density. For the case of the estimation of the relative phase θ between two interfering wave-packets we demonstrate that the sensitivity can scale as $\Delta^2\theta \propto N^{-1.33}$ with the total number of particles N when phase-squeezed states are used. The necessary amount of squeezing could be created using a Bose-Einstein Condensate trapped in a double-well potential, and we argue that even with finite detection efficiency/resolution, sub shot-noise sensitivity can be preserved.

A 52.7 Fri 16:00 V47.01

Quantum State Tomography of Bipartite Bose Condensates

— •Roman Schmied, Caspar Ockeloen, and Philipp Treutlein — Departement Physik, Universität Basel, Schweiz

The quantum-mechanical states of large systems are difficult to measure experimentally because of the exponentially large number of variables involved. Yet in systems of indistinguishable bosons, this number is dramatically reduced, and a tomographic reconstruction of the exchange-symmetric density matrix is feasible even for thousands of particles. We present a practical method for experimentally performing this tomography for two-component Bose–Einstein condensates,* and extend it to the tomographic determination of *correlations* between small numbers of particles within a condensate: such correlations can be stable even when the total atom number fluctuates between experimental runs. The tomographic reconstructions of Wigner functions, Glauber–Sudarshan P-representations, and Husimi-Q distributions on the Bloch sphere are compared.

As an application we present the quantum-state tomography of spin-squeezed states of a two-component ^{87}Rb Bose–Einstein condensate (see also SYQM 1.5).

* R. Schmied and P. Treutlein, New J. Phys. **13**, 065019 (2011)