A 48: SYQM 1: Quantum limited measurement applications 1

Time: Friday 10:30–12:45 Location: V47.01

Invited Talk A 48.1 Fri 10:30 V47.01

Overview of some recent "atomic-physics" experiments with nitrogen-vacancy centers in diamond — •Dmitry Budker — University of California, Berkeley, USA 94720-7300

I will report on several recent measurements conducted by our group and our collaborators on NV-center ensembles, including a systematic study of spin-relaxation processes, pump-probe spectroscopy of singlet states, the "light-narrowing" effect, and optical polarization of large ensembles of nuclear spins. Up-to-date bibliography related to this work can be found at http://budker.berkeley.edu/PubList

Invited Talk A 48.2 Fri 11:00 V47.01

Quantum Limits and Quantum Enhancement in Magnetometry — Federica Beduini, Naeimeh Behbood, Yannick de Icaza, Brice Dubost, Marco Koschorreck, Mario Napolitano, Ana Predojevic, Robert Sewell, Florian Wolfgramm, and •Morgan Mitchell — ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain

Quantum Metrology uses entanglement and other quantum resources to improve the sensitivity of interferometric measurements. Strongly-interacting light-matter systems, or "quantum interfaces," offer several routes to improved sensitivity, including quantum non-demolition measurements, squeezing-enhanced optical readout of atomic sensors, and interaction-based measurements. I will describe recent experimental work that applies these quantum techniques in optical magnetometry, including sensitivity enhancements using optical entanglement, generation of squeezed states in magnetically-sensitive atomic ensembles, and interaction-based spin measurements that scale better than the so-called "Heisenberg limit" of sensitivity.

A 48.3 Fri 11:30 V47.01

Differential Magnetometry using Singlets — •Iñigo Urizar-Lanz[1], Philipp Hyllus[1], Iñigo Egusquiza[1], and Géza Tóth[1,2,3] — [1]Department of Theoretical Physics, The University of the Basque Country, P.O. Box 644, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

The gradient of a magnetic field can be measured using a single cloud of non-interacting spins, prepared initially in a state with vanishing angular momentum. The magnetic field gradient can be estimated from a measurement of the square of the angular momentum operator $\hat{J}_x$. The measurement uncertainty can then be estimated by the error propagation formula if $\langle \hat{J}_x^2 \rangle$ and $\langle \hat{J}_x^4 \rangle$ are known as a function of the gradient. We show how these quantities can be computed for the ideal state. Finally, we discuss how the results can be applied to a state close to a singlet which can be realistically prepared experimentally with a cloud of cold atoms.

A 48.4 Fri 11:45 V47.01

Ultimate quantum bounds on mass measurements with a nano-mechanical resonator — •Daniel Braun — Université de Toulouse, UPS, Laboratoire de Physique Théorique (IRSAMC), F-31062 Toulouse, France — CNRS, LPT (IRSAMC), F-31062 Toulouse, France

I establish the ultimate lower bound on the mass that can be measured with a nano-mechanical resonator in a given quantum state based on the fundamental quantum Cramér–Rao bound, and identify the quantum states of the oscillator which will allow the largest sensitivity for a given maximum energy. I show that with existing carbon nanotube resonators it should be possible in principle to measure a thousandth of the mass of an electron, and future improvements might allow to reach a regime where one can measure the relativistic change of mass due to absorption of a single photon, or the creation of a chemical bond.

[1] D. Braun, Eur.Phys.Lett. **94**, 68007 (2011)

A 48.5 Fri 12:00 V47.01

Entanglement-Enhanced Interferometer on an Atom Chip — •Caspar Ockeloen, Roman Schmied, Max F. Riedel, and Philipp Treutlein — Departement Physik, Universität Basel, Switzerland

We experimentally realize a Ramsey interferometer operating beyond the standard quantum limit (SQL), using two internal spin states of a two-component Bose-Einstein condensate. We first produce spin-squeezed states by controlled collisional interactions between the atoms using a state-dependent microwave near-field potential. We observe spin noise reduction by up to 4.5 dB below the SQL with a spin coherence of $> 98\%$, corresponding to a depth of entanglement of at least 40 particles.

Using such spin-squeezed states as interferometer input states, we demonstrate performance beyond the SQL. Our interferometer outperforms an ideal classical interferometer with the same number of particles (≈ 1300) for interrogation times up to 5 ms.

These experiments are performed on a micro-fabricated atom chip providing small and well-localized trapped atomic ensembles. This makes our technique promising for high-precision measurements with micrometer spatial resolution, e.g. probing near-field magnetic or microwave fields close to the chip surface.

A 48.6 Fri 12:15 V47.01

Heisenberg-limited metrology without entanglement — •Daniel Braun[1,2] and John Martin[3] — [1]Université de Toulouse, UPS, Laboratoire de Physique Théorique (IRSAMC), F-31062 Toulouse, France — [2]CNRS, LPT (IRSAMC), F-31062 Toulouse, France — [3]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, 4000 Liège, Belgium

It is common experimental practice to improve the signal-to-noise ratio by averaging many measurements of identically prepared systems. If the systems are independent, the overall sensitivity of the measurement, defined as the smallest resolvable change of the quantity under consideration, improves as $1/\sqrt{N}$. Quantum enhanced measurements promise the possibility to improve this scaling behavior. Indeed, if the N systems are initially entangled, one may achieve in principle a $1/N$ scaling of the sensitivity, known as the "Heisenberg limit". Unfortunately, decoherence has so far limited the implementation of such "quantum enhanced protocols" to small values of N. Here we show that a setup in which N quantum systems interact with a $N + 1$st system allows one to achieve Heisenberg limited sensitivity, without using or ever creating any entanglement. Local decoherence changes only the prefactor but not the scaling with N. We present a general theoretical framework for this new kind of measurement scheme, and propose a possible application in high precision measurements of the length of an optical cavity.

[1] Braun, D. & Martin, J., Nature Comm. **2**, 223, 2011.

[2] Braun, D. & Martin, J., arXiv:1005.4443.

A 48.7 Fri 12:30 V47.01

Quantum logic readout and cooling of a single dark electron spin — Fazhan Shi[1,3], Boris Naydenov[2], Fedor Jelezko[2], Jiangfeng Du[3], •Friedemann Reinhard[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart und Forschungszentrum SCoPE — [2]Universität Ulm — [3]University of Science and Technology of China, Hefei/China

The electron spin of the NV center in diamond can be polarized and read out optically. These incidental features have spawned rapidly progressing efforts to use this center for quantum information processing and magnetic sensing. However, the NV center is only one of numerous electron spin defects in diamond, most of which do not feature these attractive properties and are hence refered to as dark spins.

In my talk I present techniques to implement optical initialization and readout on these dark spins by quantum logic control. We have successfully mapped the state of a dark spin to a nearby NV center where it can be read out optically. Using this technique, we have performed pulsed electron spin resonance experiments on a single dark spin. Moreover, we were able to cool a dark spin by swapping its state with a nearby polarized NV.

These two results allow to extend the NV center's two key properties - optical spin polarisation and readout - to any electron spin in its vicinity.