Next-Generation Sensors for Neuromagnetism II

Organizers: Lauri Parkkonen and Justin Schneiderman

Room:# 105

Date and Time: Monday, October3 / 13:30-15:30

Neuromagnetic Measurements beyond Low-Tc SQUIDs: Session 2

MEG has provided significant insights into the workings of the human brain and improved our ability to treat it in disease. MEG has also been the main technology driver in the field of biomagnetism; to date, the low-Tc SQUID has remained the sensor of choice for MEG. However, the emerging new generation of magnetic sensor technologies enables finer-grained sampling of the neuromagnetic field bothat the head surface for on-scalp MEG and within the neural tissue for invasive magnetoneurography. By moving beyond the limitations of low-Tc SQUIDs, these new approaches hold promise for major advancements over the state of the art in neuromagnetic recordings: the substantial increase in spatial resolution and signal-to-noise ratio as well as access to neuron-scale magnetic signals may drastically change our field. This symposium will not only provide an up-to-date picture of several sensor technologies that may rival low-Tc SQUIDs in neuromagnetism but it will also illustrate the value of these novel technologies for MEG. In addition, the symposium covers the challenges in moving from demonstrations with single sensors to practical systems.

Speakers:

- **Visa Vesterinen** (VTT Technical Research Center of Finland, Finland)
  "The Kinetic Inductance Magnetometer"

  Commercially established technology based on low-Tc SQUID sensors has shown its strength in ultrasensitive recordings of neuromagnetic signals. The SQUIDs are based on the Josephson effect in superconducting tunnel junctions leading to a nonlinear response of magnetic signals. We present here an alternative, the kinetic inductance magnetometer (KIM), based on the intrinsic magnetic nonlinearity of the superconducting material itself [1]. A benefit is that the sensors are compatible with RF multiplexed readout. Another advantage is simplicity: the magnetometers are composed of a single thin-film layer, as opposed to 5–10 layers of commercial low-Tc superconductor (LTS) fabrication processes. Furthermore, simplicity is expected to be of particular interest in the context of high-Tc (HTS) devices. HTS SQUIDs have not reached the technological maturity needed in routine production of large sensor arrays though HTS technology has large potential in terms of simpler cryogenics such as miniaturized closed-cycle cryocoolers. In this presentation, we will show the first experimental results obtained with HTS KIMs. We will also review our previous results with LTS KIMs currently reaching electronics-limited magnetic field noise level at about 30 $fT/Hz^{1/2}$, and a dynamic range of 600 nT. We also provide an update about electronics.
  [1] J. Luomahaara et al., Nat. Commun. 5, 4872 (2014)

- **David A. Simpson** (Univ. of Melbourne, Australia)
  "Exploring magnetism in biology using defects in diamond"

  Magnetic resonance spectroscopy techniques have changed the face of biomedical research and our view of the human body to the point where electron spin resonance (ESR), nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) now permeate most areas of clinical science and research. State-of-the-art MRI technology has recently demonstrated sub-millimetre imaging resolution, but if the sub-cellular worlds of biology and chemistry are to be fully explored, a transformative shift in technology is needed. In this presentation I will describe how an atomic-sized nitrogen vacancy (NV) defect in diamond can be used to image magnetic signals emanating from biological systems. In particular, I will detail our journey in applying this quantum system to interesting magnetic detection problems and show how the fragile decoherence of the NV electronic spin can be exploited to detect weak magnetic fields. Finally, I will describe our recent work in scaling this technology up to image magnetic nanoparticles and the electron spin resonance signals from paramagnetic molecules in solution over wide fields of view with diffraction limited resolution.

- **Myriam Pannetier-Lecoeur** (CEA Saclay, Gif-sur-Yvette, France)
  "Spintronics sensors for biomagnetism at neuron scale"

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- **Elena Boto** (Univ. of Nottingham, UK)
  "The Potential of Optically-Pumped Magnetometers for MEG"

  MEG remains limited by low spatial resolution and sensitivity, caused by both the inherently small magnetic fields generated by the brain and the relatively large scalp-to-sensor distance. The latter is limited in current systems due to a requirement for detectors operating at low temperature. However, this could be overcome using optically-pumped magnetometers (OPMs), which have the advantage that they can be brought to within few millimetres of the scalp, thus offering increased sensitivity. In this talk I will first present the results of simulations in which we quantify the advantages of hypothetical OPM systems in terms of sensitivity, reconstruction accuracy and spatial resolution. We show that a multi-channel whole-head OPM system would offer up to an order of magnitude improvement in sensitivity for an adult brain as well as clear improvements in reconstruction accuracy and spatial resolution. However, I also show that such improvements depend critically on accurate forward models; indeed, reconstruction accuracy of the OPM system outperformed that of a SQUID only if the forward field error was less than 5%. Secondly, I will present our first experimental study, showing evidence that commercial OPMs are able to accurately characterise stimulus evoked and induced (oscillatory) changes in the human magnetoencephalogram.

- **Lauri Parkkonen** (Aalto Univ., Finland)
  "From sensors to a MEG system"

  Recent developments in magnetic sensing have made it feasible to record MEG signals within millimeters from the scalp and allow sensor arrays adaptable to the head size and shape of each individual and even to the research question at hand. While this flexibility may drastically improve the signal-to-noise ratio, it calls for methods to optimize the sensor locations, to accurately measure the actual sensor locations and sensitivity directions with respect to the head, and to adapt external interference suppression systems to each measurement. Here, I will discuss these aspects that need to be tackled when moving from demonstrations with single sensors to a robust multichannel system that can be operated in standard magnetically shielded rooms. I will also present our simulations on optimizing such on-scalp arrays for picking up brain signals and for rejecting external interference.