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Education

2014 **PhD in Physics** **University of Nottingham**
Title: Scanning Probe Microscopy from the Perspective of the Sensor
Supervisor: Prof. P. Moriarty

2010 **BSc. (Hons) Physics, First Class** **University of Nottingham**

Research Positions

March 2016–Present **Post-doctoral Researcher** **Joint Quantum Institute, University of Maryland**
Currently I am working on a precision measurement of the universal gravitational constant, G. This project uses a torsion balance designed at the BIPM (Bureau international des poids et mesures). During the first year of the project I am replacing all of the software for data collection and analysis, replacing much of the electronics, repairing some hardware, and writing code to model the experiment so that G can be calculated. A first measurement is planned at the end of the first year of the project, after this the some of the mechanical hardware will be modified for a second measurement campaign. The work is being performed at NIST, in collaboration with Clive Speake at the University of Birmingham.

March 2014–March 2016 **Guest Researcher** **NIST**
I had a two year research position in the NIST Mass and Force group. The work was varied from developing and characterising novel AFM sensors, to optomechanical force measurements both at the femtonewton and the micronewton scale. Another project was upgrading the software and experimental methods of the NIST electrostatic force balance, an instrument which can measure millinewton forces with an accuracy of a few parts per million, traceable to quantum standards.

August–October 2012 **Marie Curie Fellow** **Eindhoven University of Technology**
I had a short fellowship at TU/e in Prof. P.M. Koenraad's group. My work centred around troubleshooting and improving the low temperature magnetic force microscope they were developing in collaboration with Attocube Systems.

April–May 2012 **Guest Researcher** **NIST**
A one month placement taking laser Doppler vibrometry measurements of qPlus AFM sensors to experimentally verify my work on their dynamics.

Academic Awards and Prizes

Silver, Humies Awards 2012: International award for genetic and evolutionary computation which produces human competitive results. Awarded at the Genetic and Evolutionary Computation Conference (GECCO) 2012

2010 Nottingham Physics Graduation Prizes:

- University Prize — Highest final average mark (88%) for all courses in the School of Physics.
- Bill Moore Prize — Outstanding ability in Experimental Project work.
- Barton Prize — Highest average mark on the Physics BSc. course.

1st place, Tessella Poster Prize 2011: An annual poster competition for postgraduates in the Nottingham University School of Physics and Astronomy

Nominated, Institute of Physics' "Very Early Career Physics Communicator Award" 2012: One of four short-listed finalists who presented their experience in public outreach at the award ceremony.

Research Experience and Skills

Instrumentation for precision measurements: Much of my scientific experience is concentrated around instrumentation, as the intricacies of what we don't know are often held in the subtleties of what we can't yet measure. My early research in scanning probe microscopy (SPM), started as an undergraduate building a vacuum compatible scanning tunnelling microscope, and progressed towards designing optomechanically driven force sensors with 14 femtonetwon resolution for use in atomic force microscopes. Progressing from SPM into precision force metrology, I worked on the NIST electrostatic force balance (EFB). My work on this lead to significant improvements in accuracy and precision of milligram level forces, compared to traditional mass metrology. Having honed my instrumental abilities working in metrology, I have moved back to more fundamental physics. Disagreement between measurements of the universal gravitational constant are most often explained by unnoticed experimental bias, however, until these disagreement are reconciled the exciting possibility of undiscovered physics cannot be dismissed.

Programming Skills: I am an experienced and competent programmer familiar with a number of different languages and programming styles. Currently I am working efficient algorithms for calculating gravitational forces between arbitrary objects in C. I am also developing software for my G measurement mainly in python and C, with some Bash for automation tasks, and Octave for analysis. Previously I wrote the control software for the NIST EFB in LabView Real time, connected to a host LabView system with custom C drivers for some USB hardware. During my PhD I developed software in C++ and MATLAB which implements a combination of image recognition and machine learning techniques to control a STM. This software is able to automatically achieve atomic resolution in both ambient and vacuum environments. This work won Silver in the 2012 Humies Award for "human-competitive results produced by genetic and evolutionary computation", and was published in Applied Physics Letters. The image analysis routines developed as part of this work have been released as an open source MATLAB toolbox. The performance of the toolbox was assessed in Review of Scientific Instruments.

Teaching and Outreach Experience

2010–2016 Outreach Activities University of Nottingham and NIST
I was heavily involved with the School of Physics' public outreach programs which helps both school children and members of the public experience and get involved with physics. I have organised activities in schools, participated in events aimed at both primary school and secondary school children, lead sessions in masterclasses for 16-18 year olds. I have also participated in a number of events for the general public, including the Giants of the Infinitesimal, 'Meet the Nanoscientists' events at the Manchester Museum of Science & Industry and Magna in Sheffield. As a result of my outreach work I was short-listed for the IOP's "Very Early Career Physics Communicator Award". Since moving to NIST I have continued my outreach work demonstrating measurements of gravity and Planck's constant to people of all ages with mostly household equipment.

2012 Writing Teaching Material University of Nottingham
While demonstrating in the second year laboratory course I realised that a large number of the students struggled to understand the fundamental principles of uncertainty analysis. In response to this I wrote a guide to uncertainty analysis which is now provided to students as part of the course material for this module.

2010–2013 Postgraduate Demonstrator University of Nottingham
During my PhD I participated in the supervision of second year undergraduates for their experimental physics laboratory work. Specifically demonstrating the experiments which use MATLAB for instrument control, data acquisition, and data analysis.

Publications

- Shaw, G. A., Stirling, J., Kramar, J. A., Moses, A., Abbott, P., Steiner, R., Koffman, A., Pratt, J. R., and Kubarych, Z. J., *Milligram mass metrology using an electrostatic force balance*, Metrologia, **53**, A86 (2016) DOI: 10.1088/0026-1394/53/5/A86
- Sweetman, A., Stirling, J., Jarvis, S.p., Rahe, P., and Moriarty, P., *Measuring the reactivity of a silicon-terminated probe*, Physical Review B, **94**, 115440 (2016) DOI: 10.1103/PhysRevB.94.115440
- Melcher, J., Stirling, J., Shaw, G. A., *"A simple method for the determination of qPlus sensor spring constant's"*, Beilstein Journal of Nanotechnology **6** 1733 (2015) DOI: 10.3762/bj-

nano.6.177

- Melcher, J., Stirling, J., Guzmán Cervantes, F., Pratt, J., Shaw, G. A., *"A self-calibrating optomechanical force sensor with femtonewton resolution"*, Applied Physics Letters, **105**, 233109 (2014) DOI: 10.1063/1.4903801
- Stirling, J., Lekkas, I., Sweetman, A., Djuranovic, P., Guo, Q., Pauw, B., Granwehr, J., Lévy, R., Moriarty, P., *"Critical assessment of the evidence for striped nanoparticles"*, PLOS One, **9**, e108482 (2014) DOI: 10.1371/journal.pone.0108482
- Stirling, J., *"Control theory for scanning probe microscopy revisited"*, Beilstein Journal of Nanotechnology, **5**, 337 (2014) DOI: 10.3762/bjnano.5.38
- Stirling, J., Woolley, R. A. J., Moriarty, P., *"Scanning probe image wizard: A toolbox for automated scanning probe microscopy data analysis"*, Review of Scientific Instruments, **84**, 113701 (2013) DOI: 10.1063/1.4827076
- Stirling, J., *"Optimal geometry for a quartz multi-purpose SPM sensor"*, Beilstein Journal of Nanotechnology, **4**, 370 (2013) DOI: 10.3762/bjnano.4.43
- Stirling, J., Shaw, G. A., *"Calculation of the effect of tip geometry on non-contact atomic force microscopy using a qPlus sensor"*, Beilstein Journal of Nanotechnology, **4**, 10 (2013) DOI: 10.3762/bjnano.4.2
- Woolley, R. A. J., Stirling, J., Radocea, A., Krasnogor, N., Moriarty, P., *"Automated probe microscopy via evolutionary optimization at the atomic scale"*, Applied Physics Letters, **98**, 253104 (2011) DOI: 10.1063/1.3600662

Selected Conference Presentations

- "Upgrading the NIST Electrostatic Force Balance" — Conference on Precision Electromagnetic Measurements, 10–15 July 2016
- "A self-calibrating optomechanical force sensor with femtonewton resolution" — 18th International Conference on non-contact Atomic Force Microscopy, 7–11 September 2015
- "SPIW: A MATLAB toolbox for automated SPM image analysis" — UK SPM 2013, 27–27 June 2013
- "Inherent coupling of lateral and normal forces in qPlus AFM" — 15th International Conference on non-contact Atomic Force Microscopy, 1–5 July 2012
- "Inherent coupling of lateral and normal forces in qPlus AFM" — Atomic structure of nanosystems from first-principles simulations and microscopy experiments, Physics Boat Workshop, 15–17 May 2012