Jack Griffiths*
Dr. Tom Bland, Prof. Nick Proukakis
School of Maths, Stats and Physics
*j.griffiths2@ncl.ac.uk

Metastability in a prototype atomtronic circuit

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1 ATOMTRONICS

Atomtronics — an emerging area of ultra-cold, atomic physics — exploits the charge neutrality of atoms to create circuits analogous to those found in electronic systems. A foundation for atomtronic systems are *Bose-Einstein Condensates*.

At low temperatures, weakly interacting, low density atoms condense into one "superatom". This is Bose-Einstein Condensation — a state of matter (which is essentially a "superfluid") predicted by Bose and Einstein in 1924. Its experimental realisation won the 2001 Nobel Prize in Physics[1].

2 QUANTUM TECHNOLOGY

Quantum techology is the intersection of physics and engineering, realising practical applications of quantum mechanics — the theory underpinning nature at very small scales (such as atoms or electrons).

Quantum technology spans areas such as sensors and next-generation communications ensuring secure encryption in the advent of ultra-high performance quantum computers.

Governments and companies are investing heavily in quantum technology[2]. The work at the Newcastle–Durham Joint Quantum Centre (JQC) and elsewhere is pivotal in advancing such technology.

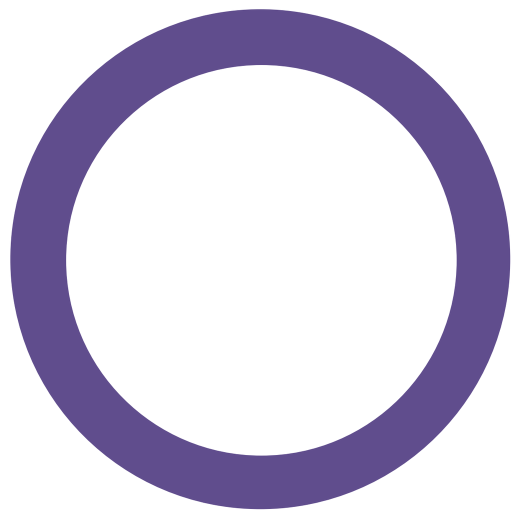
3 ATOMIC SQUID

Superconducting QUantum Interference Devices (SQUID) are ultra-sensitive sensors for measuring very small magnetic fields (e.g., in the brain).

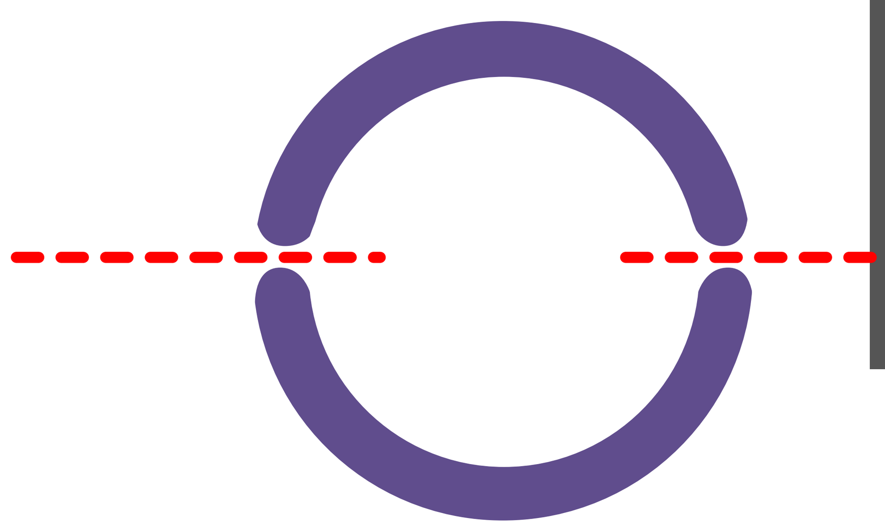
Atomic SQUID are ultra-sensitive sensors for measuring very small *rotations* (e.g., in spacecraft)

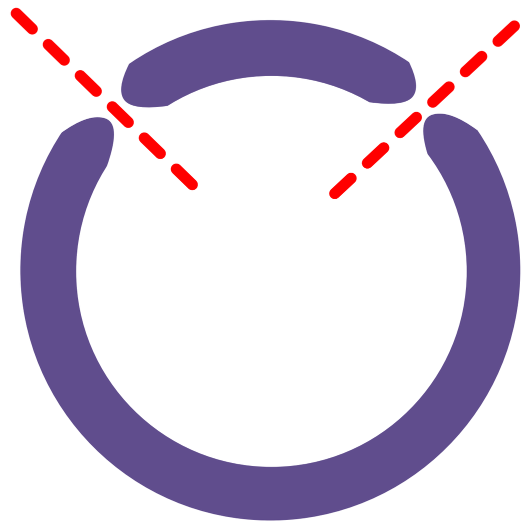
In this work, a theoretical model of an experimentally realised, state-of-the-art atomic SQUID by Los Alamos National Laboratory[3] was simulated. The theoretical model produced a proof-of-principle atomic SQUID, which is an emerging *quantum technology*.

4 THEORETICAL SETUP



- Use a **doughnut/ring-shaped** geometry to trap the atoms
- Flood the ring with **Rubidium-87** atoms — they form Bose-Einstein condensates easily
- Cool to -273.15 °C ("absolute zero") to ensure only the condensate exists to improve device sensitivity
- Fire a laser on either side to form a **Josephson junction**: a connection between two condensates which permits the flow of superfluid only
- Accelerate the lasers for 60ms, then move them at a constant velocity for 32.5ms then stop instantaneously



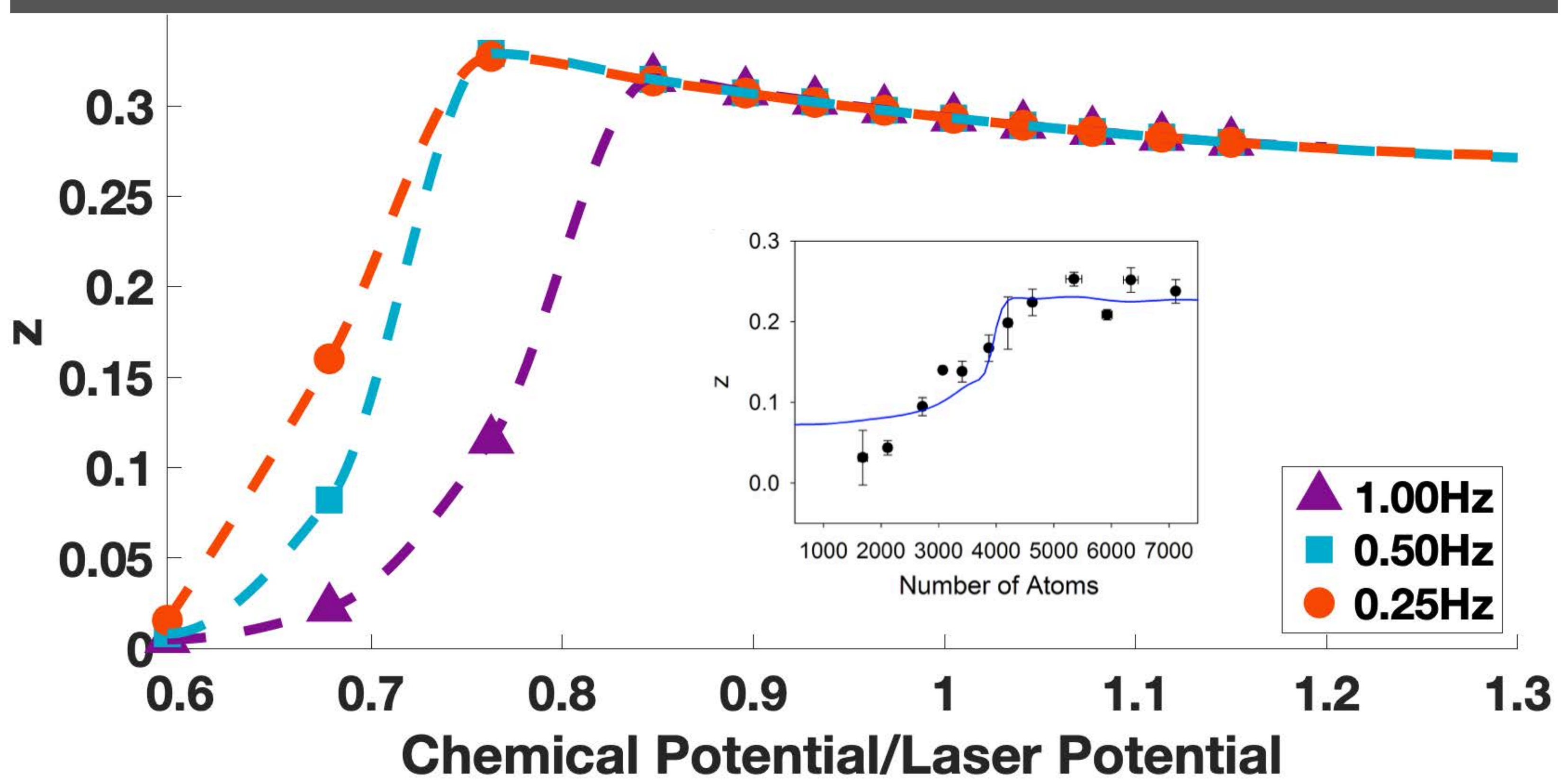


- Measure the number of atoms on the top and the bottom and find the population difference

$$z = \frac{N_{top} - N_{bottom}}{N_{total}}$$

5 RESULTS AND DISCUSSION

- A sudden change in z is observed for the ratio of the chemical and laser potentials being approximately 0.8. This occurs when the laser velocity is sufficiently large.
- For larger values of this potential ratio, the population difference tends to a constant value. This is consistent with oscillating, alternating atomic current from equations underpinning Josephson junction theory.
- If we know the point where z suddenly changes and the frequency of rotation of the laser, we can extract the rotation of our system with ultra-high precision.
- The results from this work (below) show excellent agreement with experimental work by Ryu, C. et al[3] (1.0 Hz inset) and the dynamics of Josephson junctions.



6 CONCLUSIONS

- A theoretical, proof-of-principle atomic SQUID was produced and allows for currently unsolved experimental problems to be simulated further
- The simulation is to be extended to consider externally applied rotation to the condensate to further explore the sensitivity of atom SQUID.
- Follow-up experiments by Los Alamos National Laboratory observed unexplained decay in the system's chemical potential as the external rotation was increased
- It is now hypothesised that there is some intrinsic system noise or issues with non-zero temperatures in experimental setups to cause such decay. It is the latter which is currently being studied in the JQC by using the simulation developed this project

ACKNOWLEDGEMENTS

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1 NobelPrize.org (2001). *The Nobel Prize in Physics 2001.* https://www.nobelprize.org/prizes/physics/2001/summary/
2 GOV.UK. (2019). *New £153 million programme to commercialise UK's quantum tech.* https://www.gov.uk/government/news/new-153-million-programme-to-commercialise-uks-quantum-tech
3 C. Ryu, et al. *Experimental Realization of Josephson Junctions for an Atom SQUID.* Phys. Rev. Lett. **111**, 20530 (2013)