W J Hughes, S Gao, E Østergaard, O Lowe, J A Blackmore, J F Goodwin, D M Lucas

Optically Heated Atomic Sources for Compact Ion Trap Vacuum Systems

william.hughes@physics.ox.ac.uk Ion Trap Quantum Computing Group – Department of Physics, University of Oxford, Oxford, UK

The drive towards scalable ion trap systems for quantum technology applications places an increasing imperative on compact and reliable subsystems with low power consumption and simple construction, particularly for vacuum-side components. We present a design for an efficient, optically-heated atomic oven, which produces a beam of calcium atoms of suitable density for rapid ion loading with modest requirements on heating laser power, easily satisfied by inexpensive diode lasers. In comparison with Joule heated ovens [1], the absence of low-resistance electrical connections permits excellent thermal isolation of the source, reducing energy delivered to the surrounding system during loading and making the source suitable for use in miniaturised or cryogenic vacuum systems. Despite its small size, the oven has an estimated lifetime of 200,000 years under continuous operation. We discuss further efforts to improve the performance of optically heated ovens and present a simple optomechanical system for rapid characterisation of atomic beam divergence.

S. Gao ***et. al.*** Rev. Sci. Instrum. **92**, 033205 (2021)

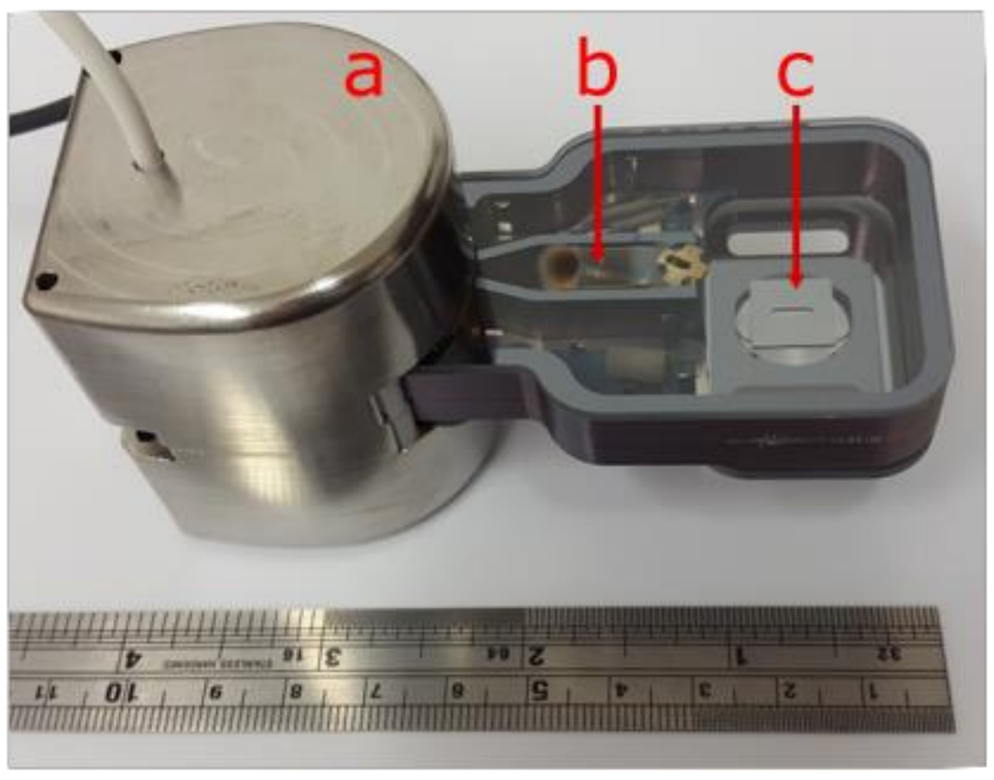
The 'MITAS' Apparatus

<$10cm^3$ UHV system containing:

- Integrated Penning cell ion pump (a)
- Miniature calcium oven (b)
- Dummy target trap (c)

Oven Characteristics:

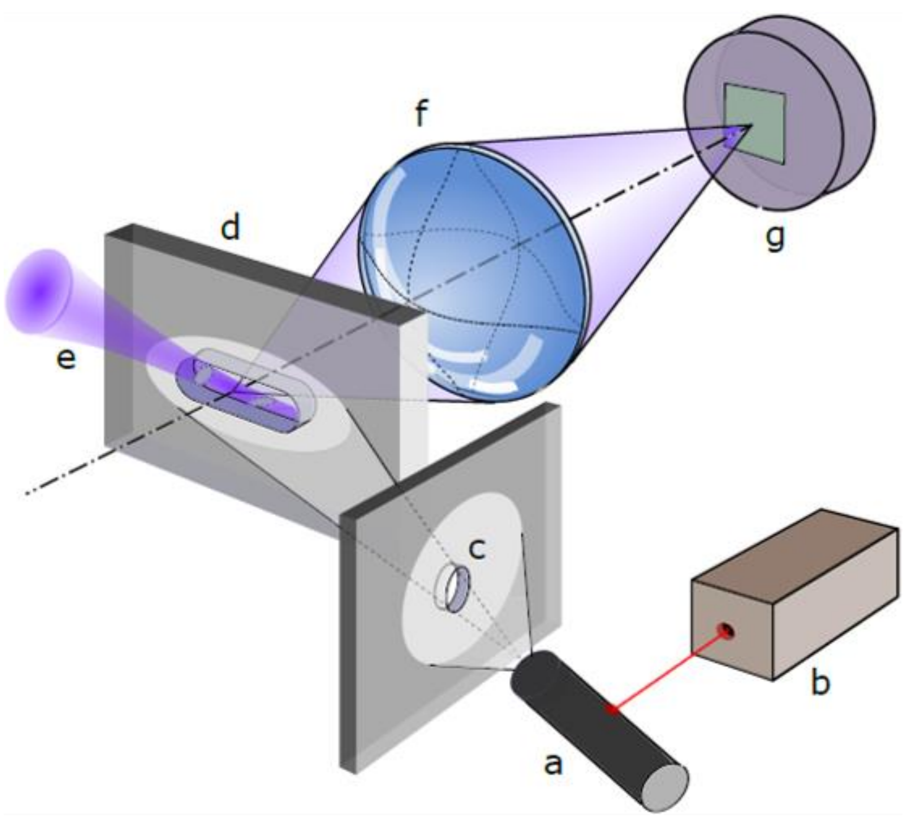
- Steel tube mounted on glass and steel supports to reduce conductive losses
- Length = 10mm; Diameter = 2mm
- Small spot on tube darkened to aid absorption of heating laser



Testing 'MITAS'

Fluorescence of neutral calcium beam used to probe oven performance

- Calcium oven (a) heated with 780nm laser (b)
- Emitted Calcium beam passes through collimator (c) to silicon wafer target (d)
- Neutral calcium beam interacts with 423nm spectroscopy laser (e)
- Fluorescence collected via NA≈0.3 lens (f) onto photon-counting PMT detector (g)



Temporal Response

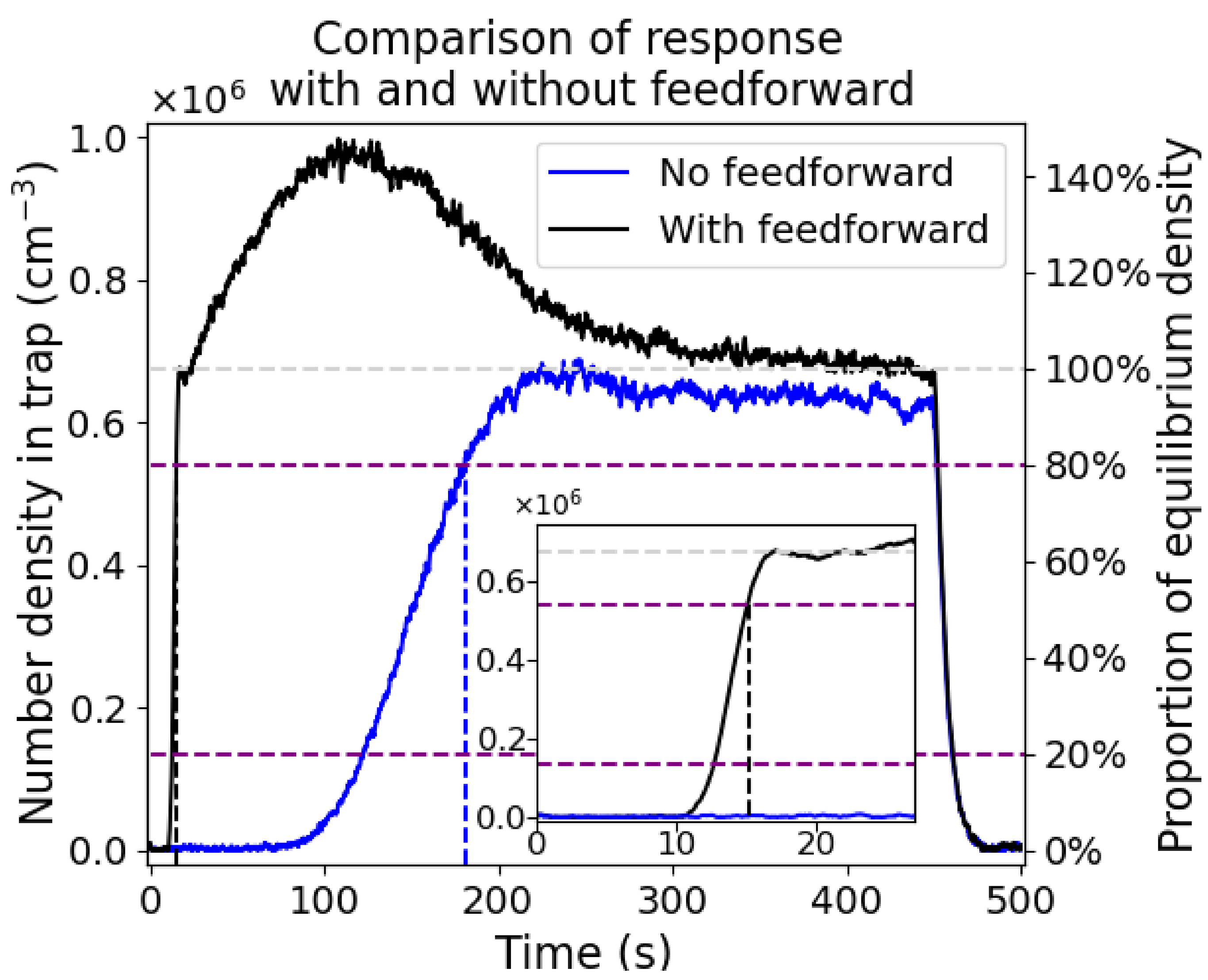
Atomic flux response of oven after onset of heating measured

Compared constant heating power of 500mW with a simple feedforward sequence designed to reduce turn on time:

0-11.5s: 3W → 11.5-18s: 0W for 6.5s → >18s: 500mW

Simple feedforward dramatically reduces turn on time of source:

Turn-on time: No feedforward: 181s Feedforward: 15s



Thermal Performance

Heating power varied and PMT count rate measured

Count rate used to infer number density and oven temperature

Relevant number densities for ion trapping are too small for a measurable fluorescence signal

Temperature dependence on optical power fitted to thermal model and extrapolated to temperatures of interest

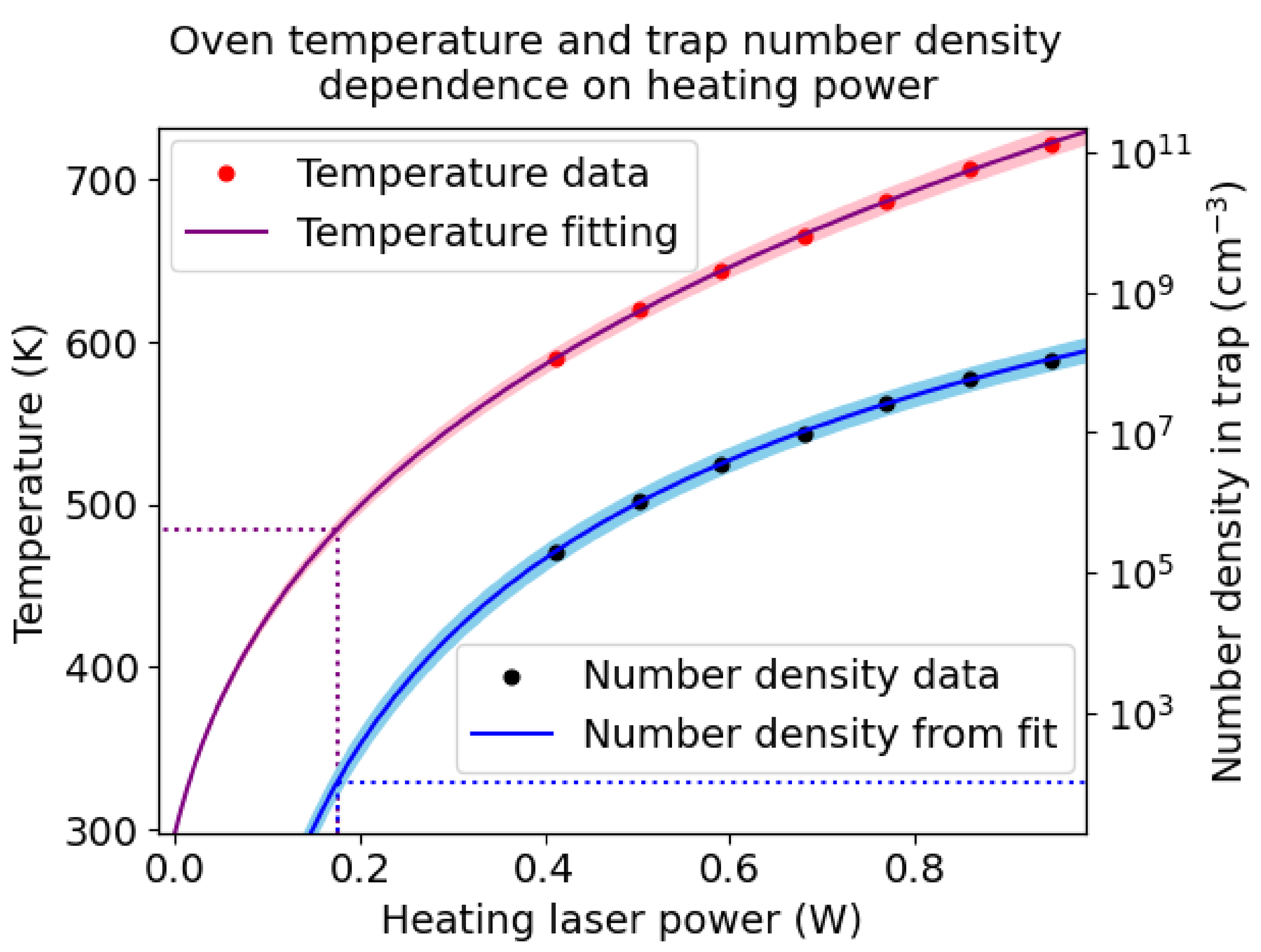
Thermal model

$$P_{laser} = \frac{P_{loss}}{\epsilon_{abs}} = \frac{K}{\epsilon_{abs}}(T - T_0) + \frac{\epsilon_{rad}}{\epsilon_{abs}}\sigma S(T^4 - T_0^4)$$

Fit results

$$\frac{K}{\epsilon_{abs}} = (5.7 \pm 6.2) \times 10^{-5}\,\mathrm{WK}^{-1}$$

$$\frac{\epsilon_{rad}}{\epsilon_{abs}} = 0.89 \pm 0.07$$



Conductive losses small at operating temperature

Predict target atom density ($100cm^{-3}$ [2]) at trap with:

- 485(1)K oven temperature
- 175(10)mW heating power

Further Progress

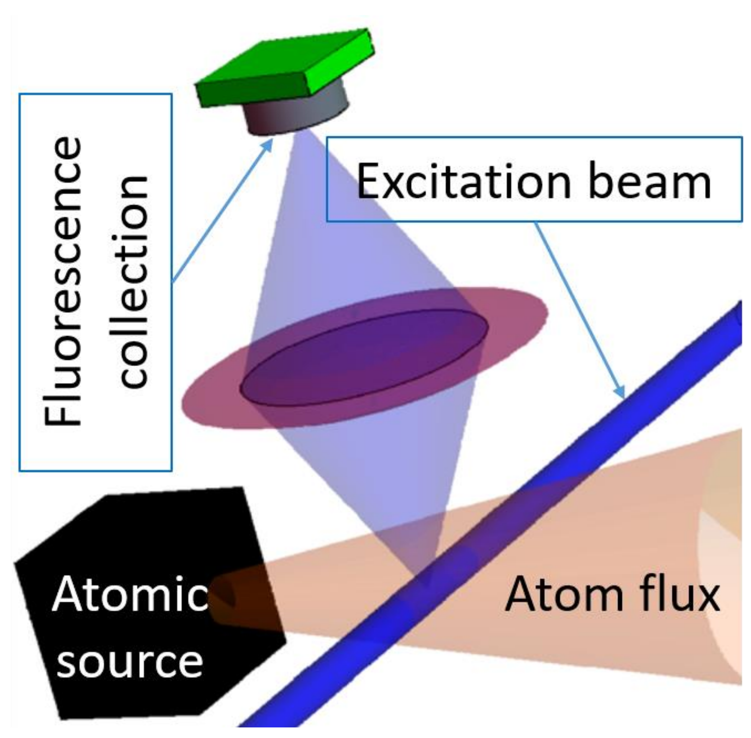
We target significant further reductions in heating power by reducing:

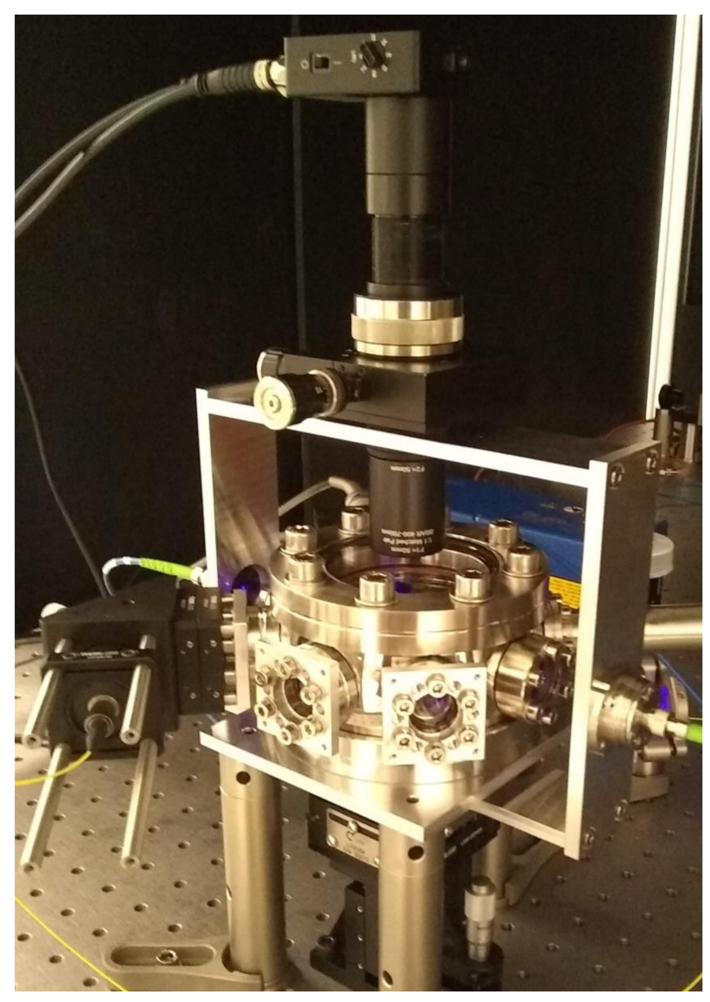
1) Size of source 2) Thermal losses 3) Distance from trap

Expected: Near-instantaneous loading with <10mW heating

Test prototypes by developing setup to test output of source

- Probe beam and imaging system scanned as a unit
- The overlap forms a movable probe of atomic density





Acknowledgements

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[1] T. G. Ballance ***et. al.*** Rev. Sci. Instrum. **89**, 053102 (2018) [2] D.M. Lucas ***et. al.*** Phys. Rev. A **69**, 012711 (2004)