Towards a compact ytterbium magneto optical trap for use in precision timekeeping applications

B. R. White[1], B. M. Sparkes[2], R. F. Offer[1], A. P. Hilton[1], X. Sun[3], W. D. A. Rickard[3], C. N. Ironside[3], and A. N. Luiten[1]

[1]Institute for Photonics and Advanced Sensing (IPAS) and School of Physical Sciences, University of Adelaide, 5005 South Australia, Australia.
[2]Defence Science and Technology Group, Edinburgh, 5111 South Australia, Australia.
[3]John De Laeter Centre, Curtin University, Bentley, 6102 Western Australia, Australia.
email: benjamin.white@adelaide.edu.au

Australian Government Department of Defence

IPAS Institute for Photonics and Advanced Sensing

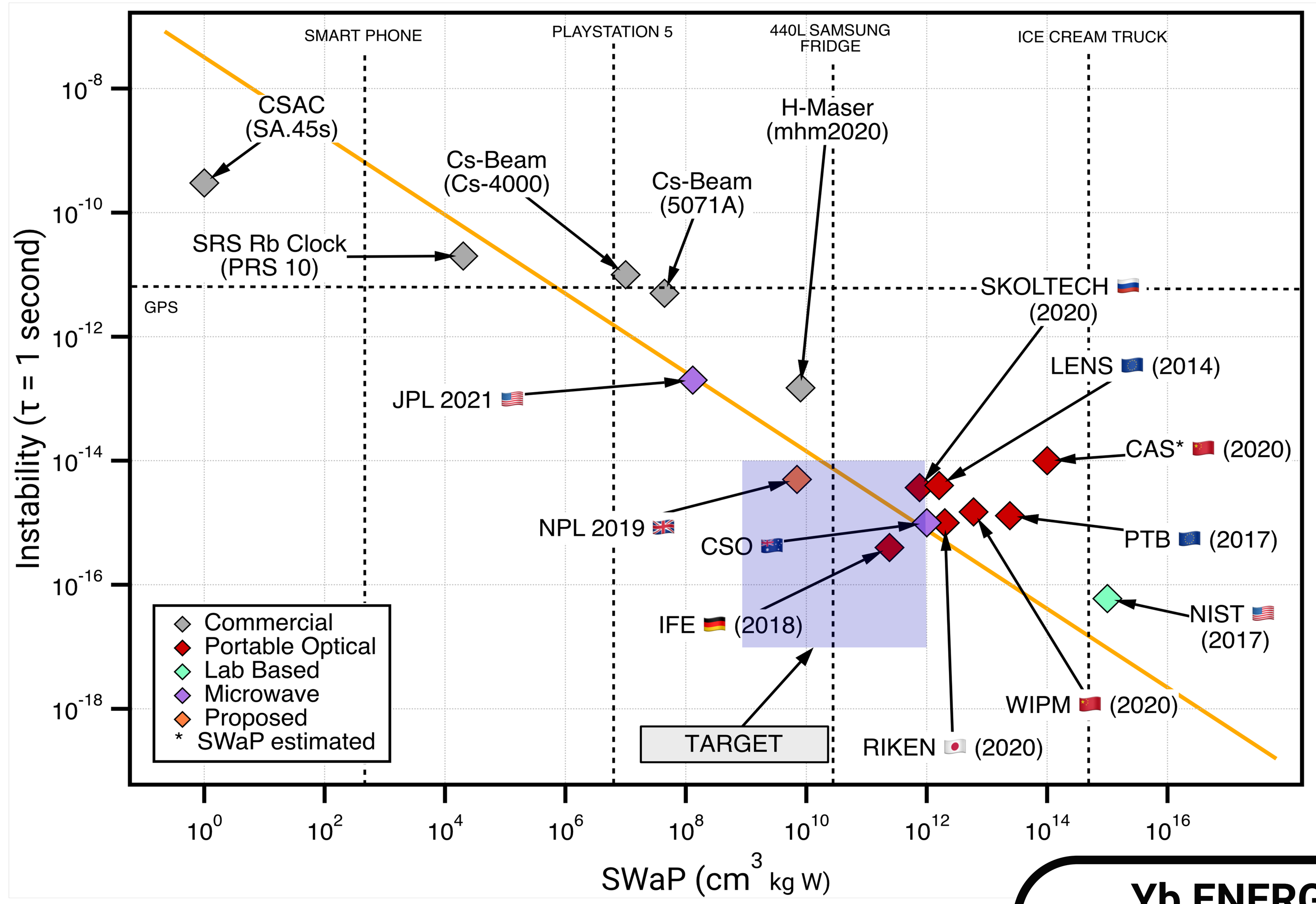
THE UNIVERSITY of ADELAIDE

Curtin University

1. CURRENT CLOCK TECHNOLOGY & GNSS TIMING RELIANCE

- Precision timing underpins and is embedded in almost **all** modern technology.
- Global Navigation Satellite Systems (**GNSS**) such as the Global Positioning System (**GPS**) disseminate precision timing signals that are **essential** for the synchronisation of power grids, the internet, financial markets, and navigation systems (to name just a few).
- **HOWEVER**, GPS is **susceptible** to **error, disruption, jamming and spoofing.**
- Over reliance on GNSS derived timing **is a serious single point of failure.**
- Lab based clock tech has orders of magnitude better performance, but still posses a **Size, Weight** and **Power** demand **(SWaP)** that prevents deployment.
- Many groups are currently attempting to bring high performance optical clock technology from the lab, to the field (Red Diamonds in Current Clock Technology Figure).
- Our work provides pathways towards reducing the reliance on GPS timing, by way of portable cold atom clocks with world class performance.
- We plan to make a **high performance portable optical clock** in the form of an **Neutral Ytterbium** (Yb^{171}) **Magneto-Optical Trap** (MOT). Target highlighted in Current Clock Technology Figure.
- Traditional MOTs are formed by 3 pairs of orthogonal counter-propagating detuned lasers. These overlap, creating a volume of space subject to the optical molasses effect in the x, y and z dimensions. Anti-Helmholtz coils create a position dependent magnetic field, creating a cold atom trap.

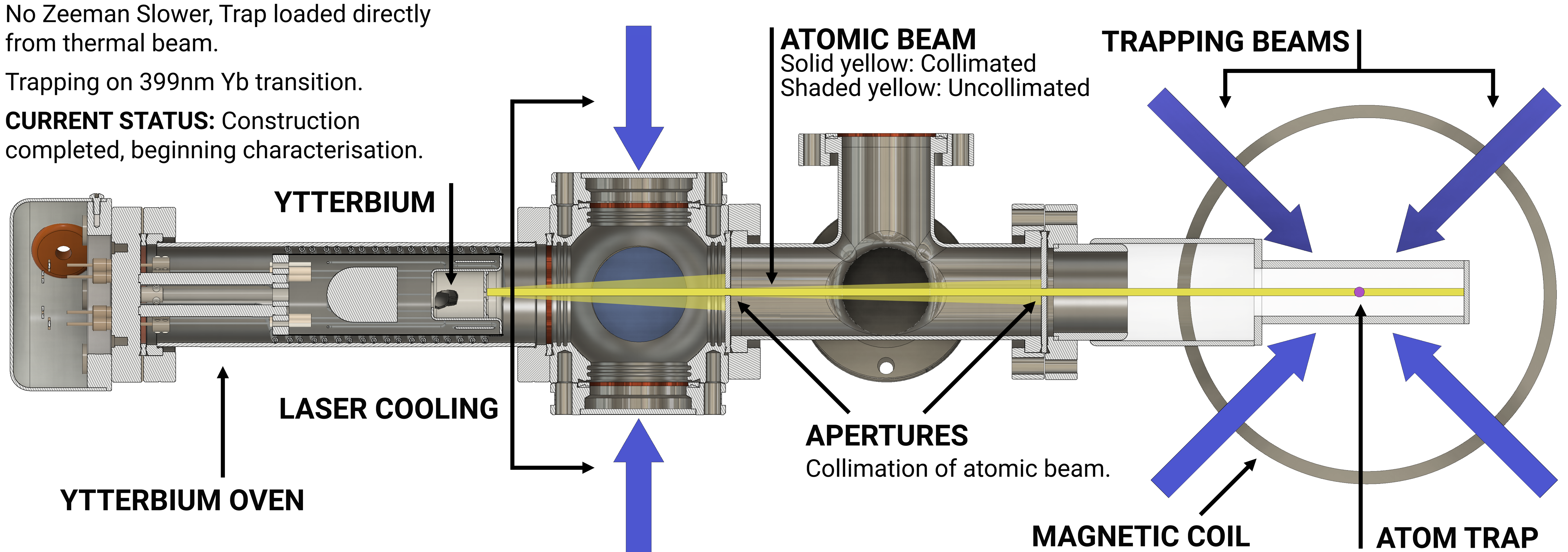
CURRENT CLOCK TECHNOLOGY: Performance vs SWaP



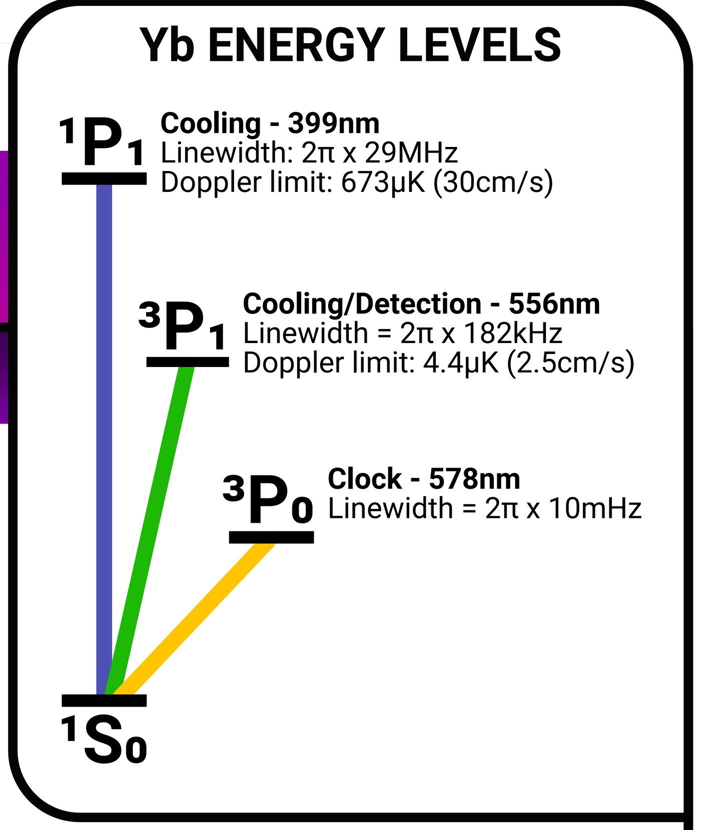
WE MUST MAKE CUTTING EDGE CLOCK TECHNOLOGY **PORTABLE. REDUCING** SIZE WEIGHT & POWER **(SWaP)** & MAINTAINING PERFORMANCE: **ACCURACY & PRECISION**

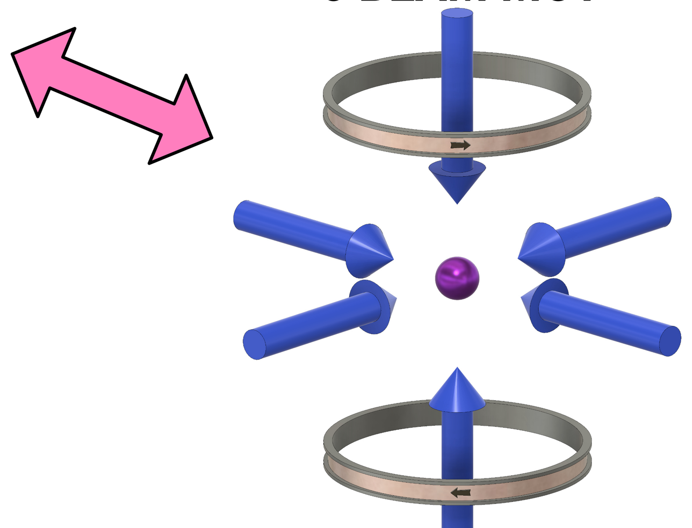
2: SIX BEAM COMPACT YTTERBIUM MOT PHYSICS PACKAGE

- No Zeeman Slower, Trap loaded directly from thermal beam.
- Trapping on 399nm Yb transition.
- **CURRENT STATUS:** Construction completed, beginning characterisation.



VIEW FROM ABOVE: SHOWN ACTUAL SIZE. LENGTH = 600mm, WEIGHT = 15kg

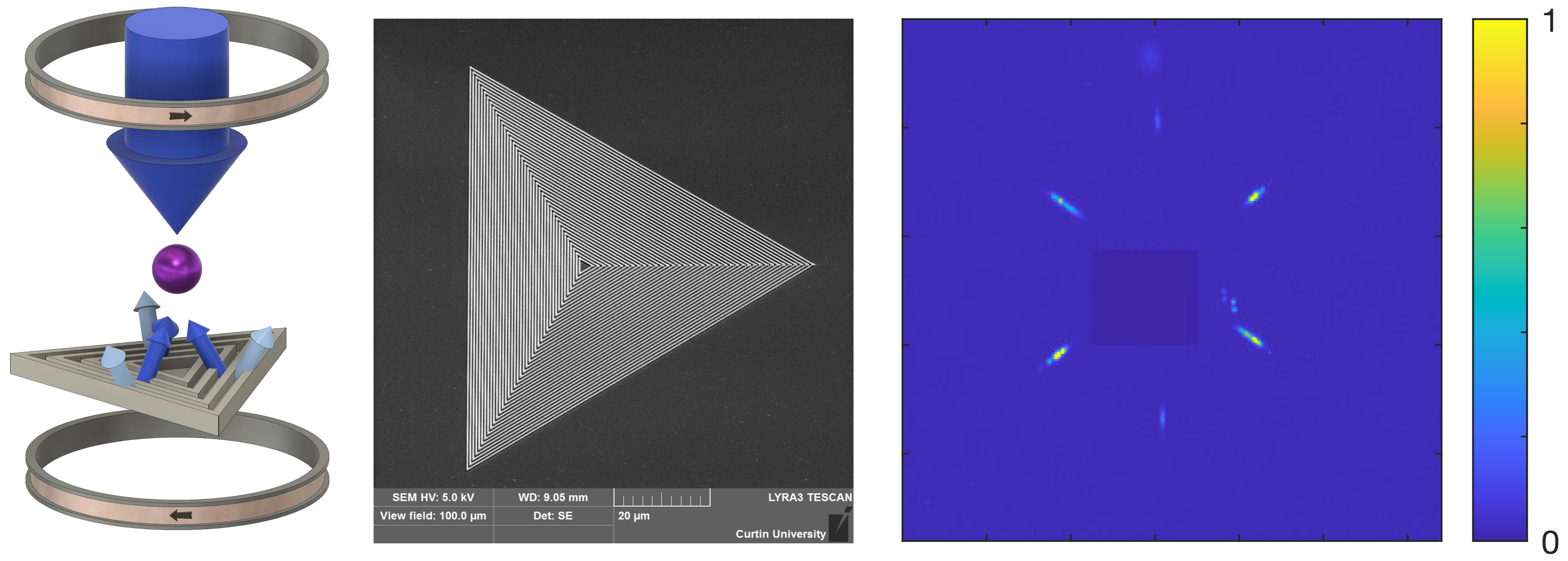




3: NEXT GENERATION: gMOT

TETRAHEDRAL GRATING MOT

(a) Overview of gMOT trap, (b) SEM image of grating, (c) Diffraction intensity



- Grating Magneto-Optical Trap (gMOT) - allows SWaP to be significantly reduced
- 6 beams replaced by a single input. Trap formed from diffracted light off grating, reducing complexity, increasing robustness and production scalability.
- Developing suitable gratings for trapping on the 399nm transition in Yb, through a collaboration between the University of Adelaide (UofA) and Curtin University (CU).
- Rapid prototyping methods developed at CU result in test gratings which are then optically assessed at UofA in an iterative process.
- Allows for fast production and testing of smaller (μm²) gratings with different coatings, patterns, and methods of construction before scaling up to the size needed (cm²) for a cold atom trap
- Results for Tetrahedral grating*: Measured (Theory)
- **Grating depth: 78nm (110nm)**
- **Diffraction angle: 43° (40°)**
- **Reflectivity: 35%, with 78% of reflected light in 1st Diffraction orders.**

* Sun, X. *et al*., accepted for publication in Optics Express (2021)

4: FUTURE PLANS

- Characterise and optimise the compact 6 beam Yb MOT.
- Integrate green and yellow spectroscopy to generate clock signals.
- Continue development of optimised Yb gratings.
- Scale up Yb gratings and begin work on the next generation compact MOT.

ENABLED BY ANFF

The authors acknowledge the Western Australian node of the NCRIS-enabled Australian National Fabrication Facility (ANFF), and the support from the Western Australian Government's Department of Jobs, Tourism, Science and Innovation. This research was funded through a Quantum Technologies Research Network Grant through the Defence Science & Technology Group, Australian Government (QT71).

Quantum Research Network
Next Generation Technologies Fund