FY23 Strategic Initiatives Research and Technology Development (SRTD)

Ultra-high flux atom source (UFAS) for precision atom interferometric sensing

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Strategic Focus Area: Quantum Sensing for Science Missions **| Strategic Initiative Leader:** Edward T Chow

Objectives:

- Generate high-flux ultracold atoms for quantum sensing applications, such as quantum gravity gradiometer (QGG) for Earth mass change missions (Fig. 1)
- Target: 10^8 Cs atoms at 1nK
- SWaP optimized for space missions

Background:

- Quantum sensing is part of the National Quantum Initiative, and NASA's quantum initiative.
- Spaceborne QGG is identified as the most promising instrument development to yield impactful result.
- QGG performance is limited by number of ultracold atoms. Required atom number: 10^8, state-of-the-art (CAL): 10^5
- Conventional method doesn't scale, need new approaches (Fig. 2)

Approaches and Results:

- Raman cooling is promising (Fig. 3):
  - 3D simulations show 1% efficiency feasible after 1000 cooling cycles (Fig. 4)
  - Critical parameter identified: the pulse duration profile
- Setting up lab apparatus (Fig. 5)
- Investigating phase readout noise of atom interferometers (Fig. 6)

Significance/Benefits to JPL and NASA:

- JPL has been leading in space quantum sensor technology and applications.
- This SRTD will position JPL in a competitive and competent position to capture the next mission opportunity deploying the first high-performance quantum sensor measurement system in space, such as QGG for mass change.

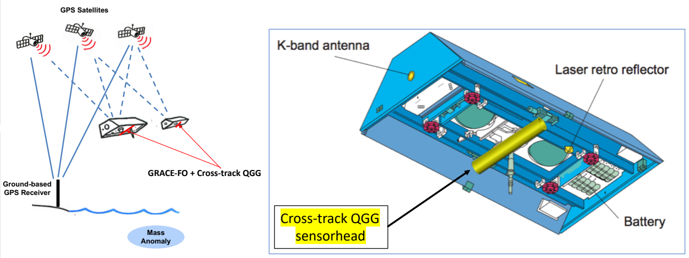

Figure 1. QGG for Earth gravity measurements

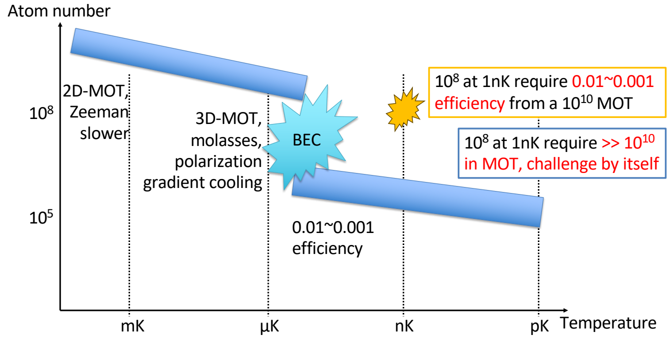

Figure 2. Paths towards an ultra high flux atom source

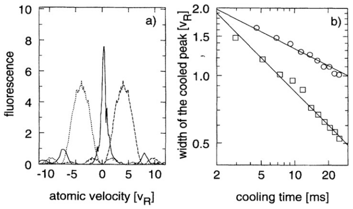

Figure 3. 1D Raman cooling demonstration, adapted from Ref [1]. (a) Dashed line: excitation profile of 30μs pulses tuned to +-4v_R. Solid line: velocity distribution after 136 repetitions. (b) Time dependence of the width of the cooled peak.

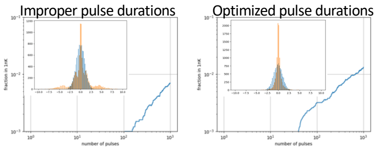

Figure 4. Fraction of atoms in 1 nK vs cooling cycles (number of pulses). Insets show population change after the first cooling cycle, from original (blue) thermal distribution (3 μK) to peaked (orange) distribution.

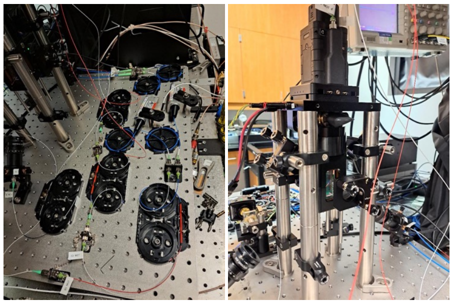

Figure 5. Pictures of the distribution part of the laser optics system, and the atomic physics package (doubleMOT) with supporting optics.

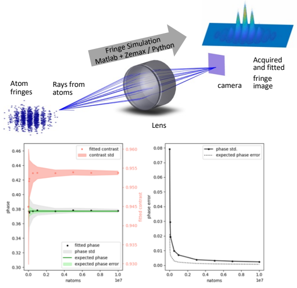

Figure 6. Phase extraction investigation. Top: simulated spatial distribution of atoms at the interferometer output (left). Each atom emitting isotropic rays imaged on a camera (right). Bottom: phase extraction and its error. Preliminary results show deviation from expected phase error.

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Reference:

[1] Reichel, J., F. Bardou, M. Ben Dahan, E. Peik, S. Rand, C. Salomon, and and C. Cohen-Tannoudji. "Raman cooling of cesium below 3 nK: New approach inspired by Lévy flight statistics." *Physical review letters* 75, no. 25 (1995): 4575.

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