An Accordion Lattice to Create Tunable Vertical Confinement in a Kagome Lattice Experiment

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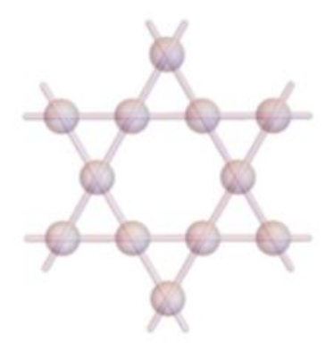
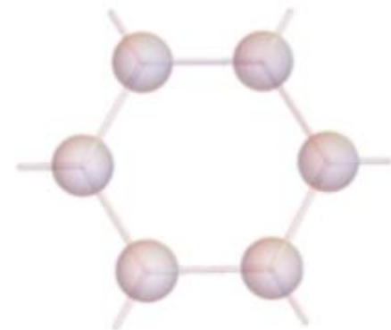
The Kagome Lattice Experiment

- Optical lattices are created by trapping atoms at nodes or antinodes of a standing wave of light
- The Kagome lattice is a 2D star shaped lattice that is "geometrically frustrated," meaning it has multiple degenerate ground states, which is interesting for condensed matter applications [1]
- The same beam setup can be used to create other interesting geometries, such as the honeycomb lattice
- The goal of this project is to upgrade the vertical lattice dimension to have tunable spacing in order to load a single layer of the vertical lattice at large spacing and then compress it to the desired confinement strength



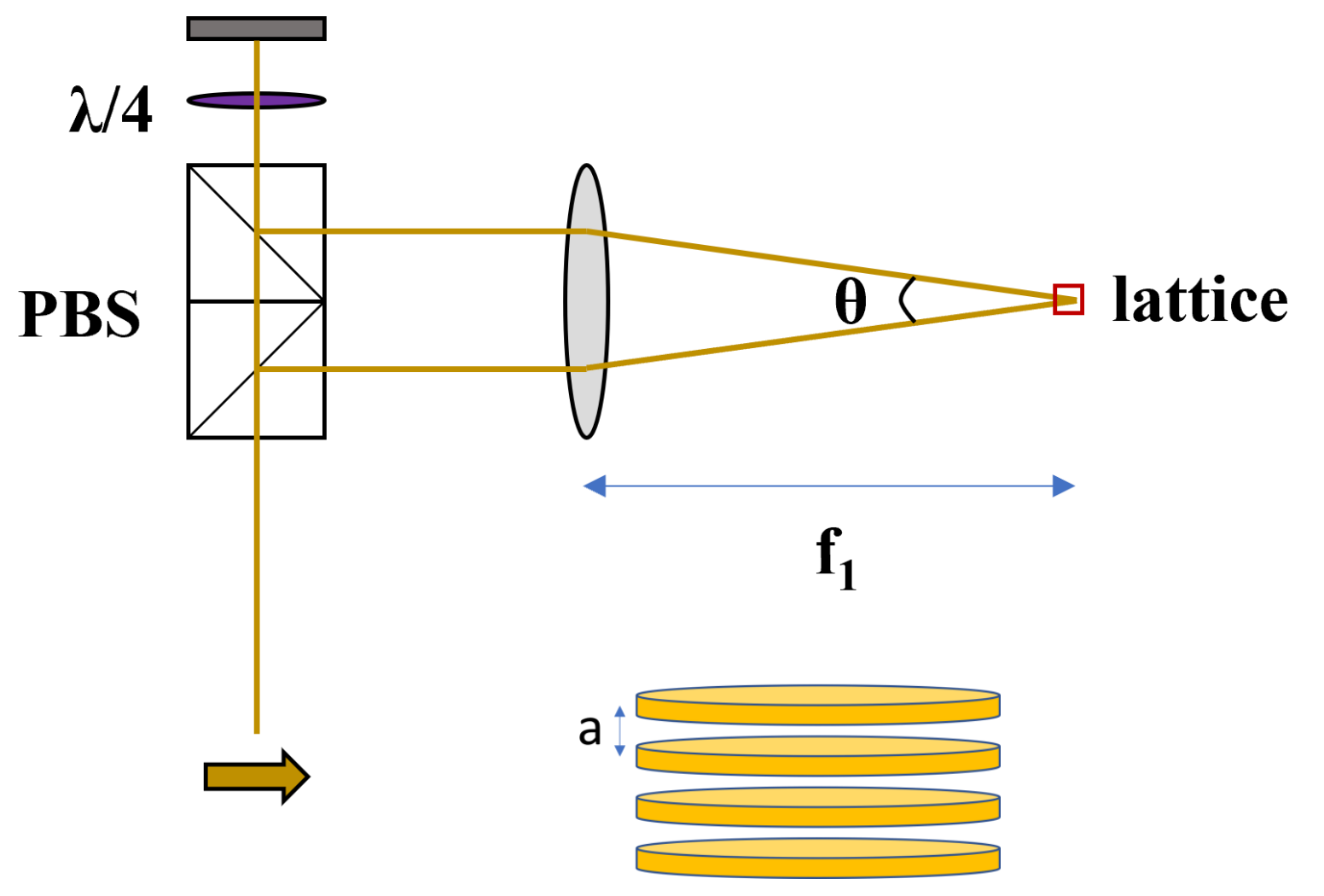
Kagome Lattice [2]



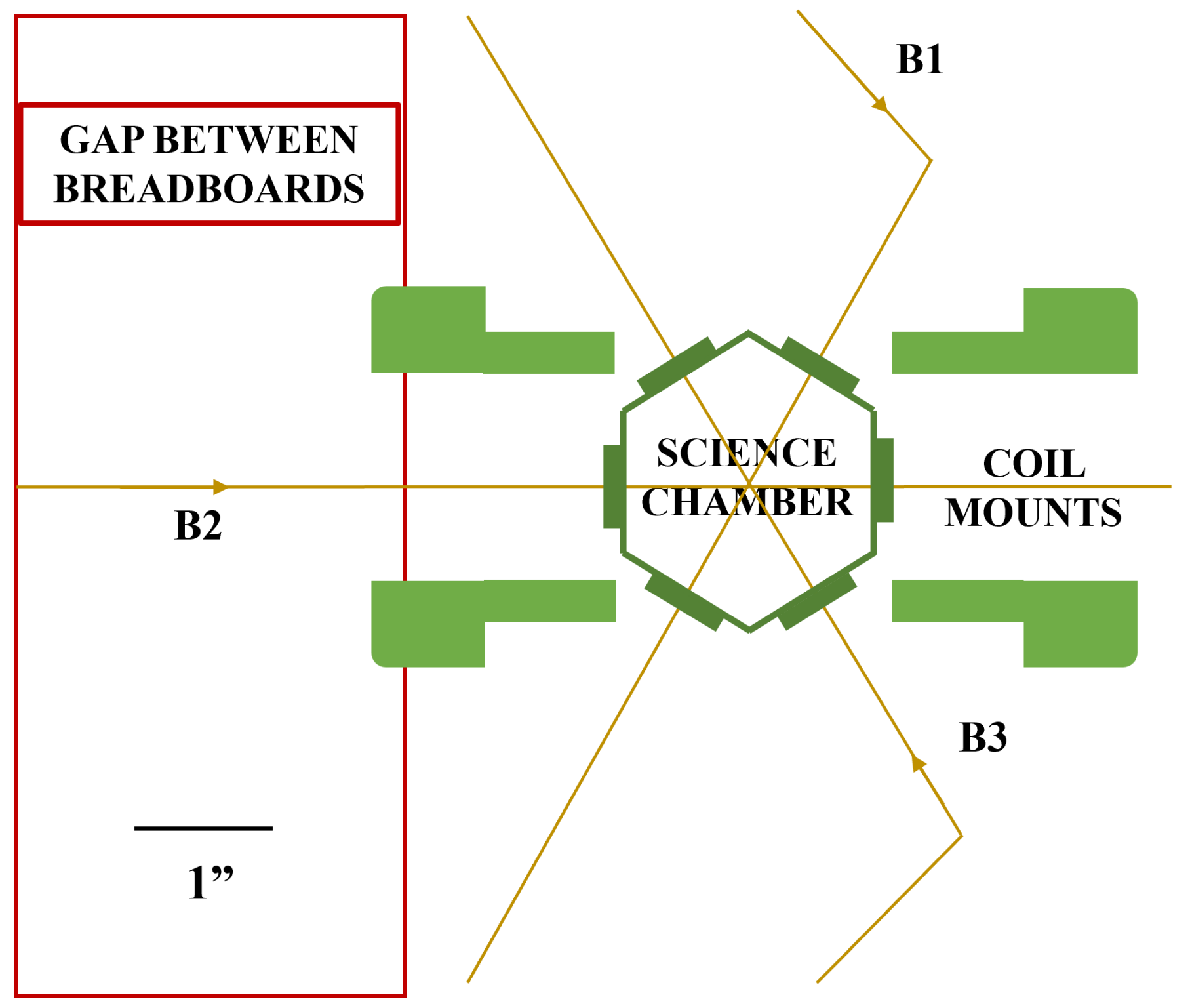
Honeycomb Lattice [2]

Accordion Lattices

- Created by interfering two coherent beams from the same laser at an angle θ [3]
- Forms a lattice in the direction perpendicular to the beams
- Lattice spacing *a* (and thus the confinement strength) can be tuned by changing the angle between the two beams



Constraints



- The Kagome lattice is currently on a raised horizontal breadboard about a foot above the optical table
- Upper horizontal breadboard is completely filled with lattice optics (beam combining, phase stabilization, amplitude stabilization, etc. for six beams)

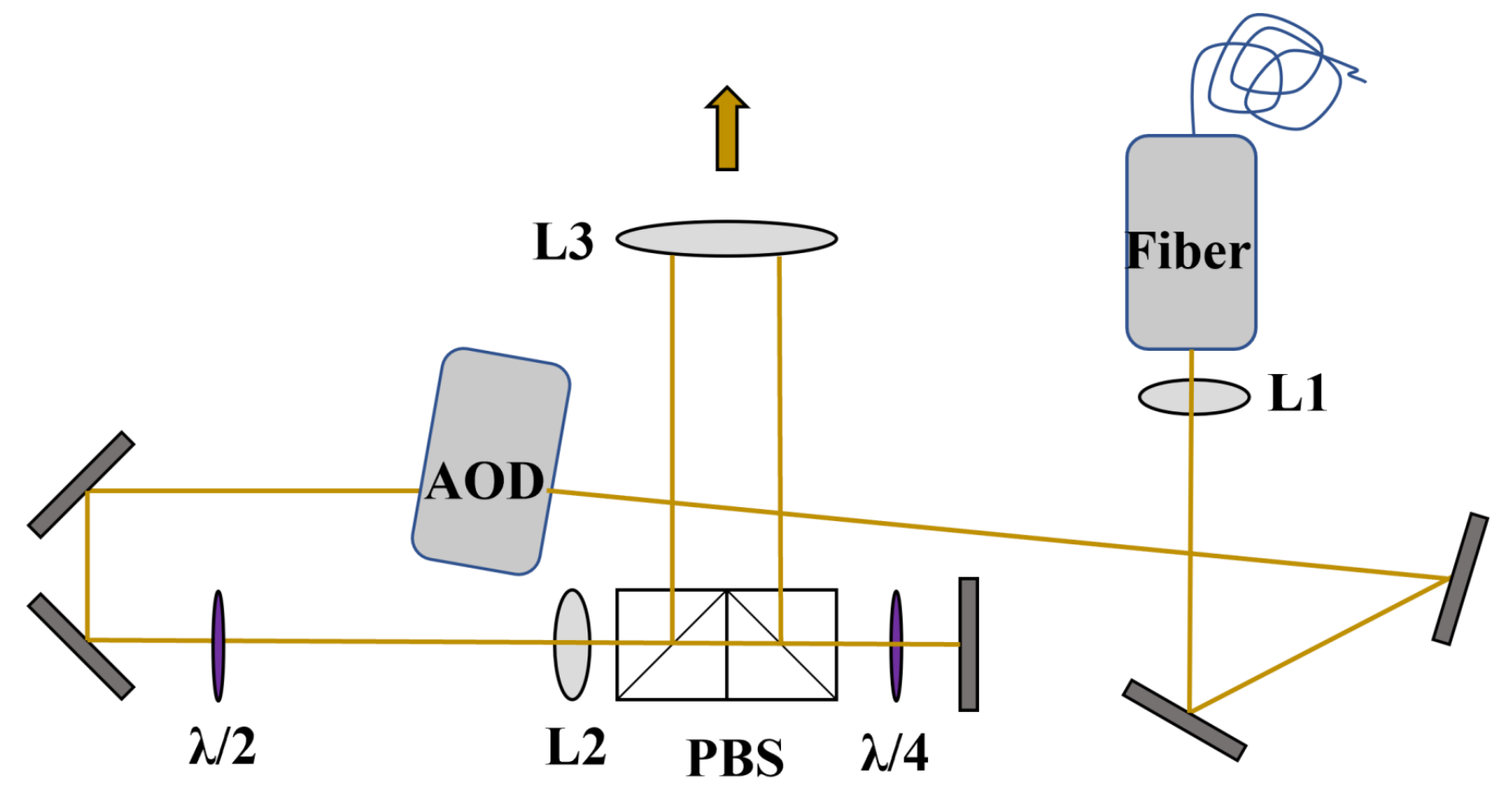
Lattice Parameters

- The most critical parameter of the accordion lattice is the minimum spacing, which determines the maximum oscillation frequency of atoms and thus the spacing between energy levels
  - The goal is to keep all of the atoms in the ground state of the vertical lattice
- This oscillator frequency ω can be approximated in the strong confinement regime by treating the lattice potential as a harmonic oscillator
- For our system (using available beam powers and a waist of 50 μm), we calculated that ω ≈ 2π x 22 kHz
- This is large enough to be safe from thermal excitations at k_bT/h ≈ 2π x 2 kHz, but is not much greater than the energy spacing of the honeycomb lattice ω ≈ 2π x 17 kHz

Optomechanical Design

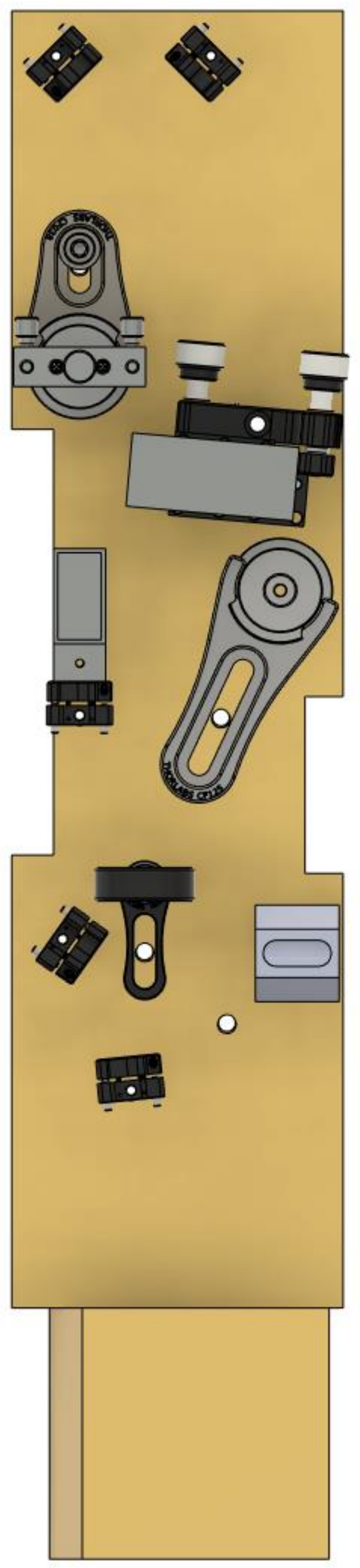
Optics

- 532 nm beam gets to breadboard through a fiber
- Beam translation accomplished by an acousto-optic deflector placed at the center of a telescope, providing 44 mrad angular deflection ≈ ½ inch translation at 250 mm (so L2 = 250 mm)
- AOM chosen over a translation stage due to the faster response time and decreased potential for vibrations
- Design is compatible with either an expanding or a 1:1 telescope around the AOM
  - This can be used to either decrease the vertical beam waist at the atoms or preserve the initial beam size
- Mirrors and AOM are attached to breadboard at fixed locations but lenses are clamped, allowing fine positioning

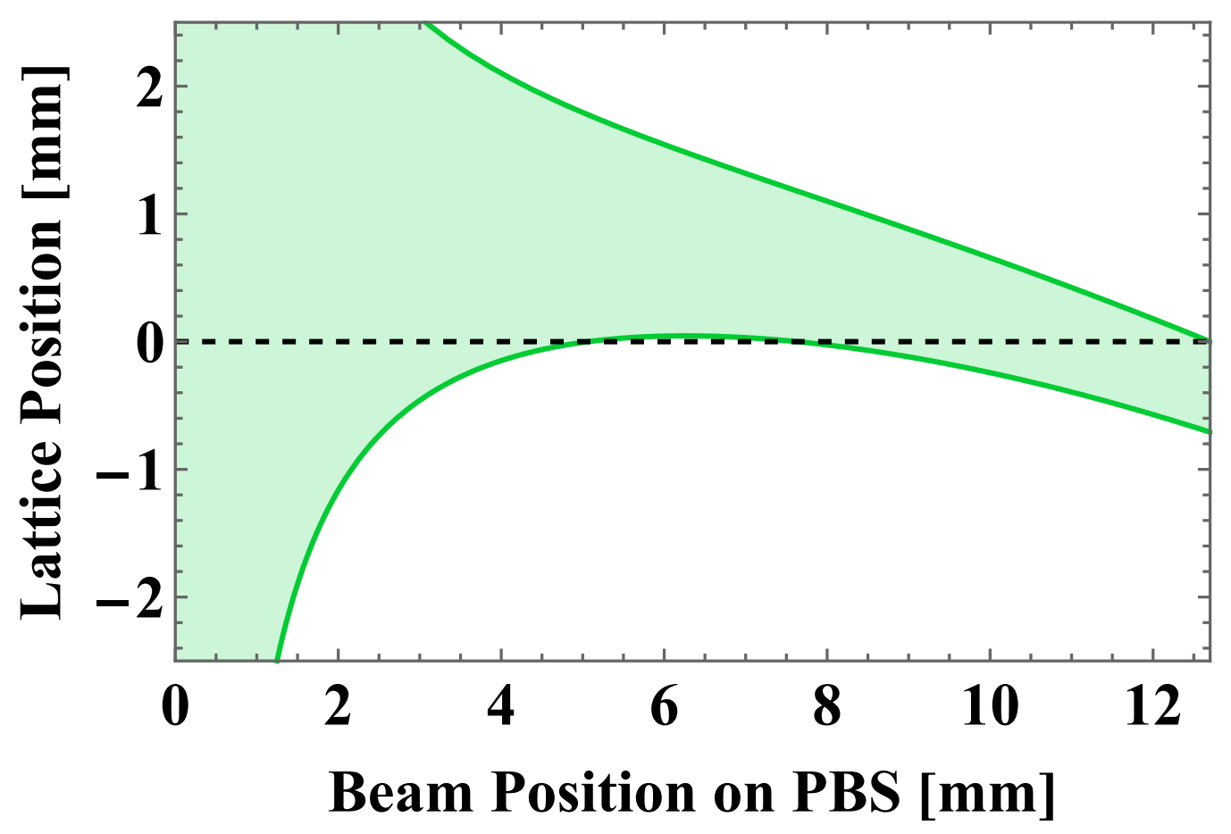


Breadboard

- Breadboard will inevitably be tall and skinny (15 ½" x 4" x ½") so needs to be as rigid as possible to damp vibrations
- Also needs to be non-ferromagnetic -> chose to use bronze
- Beam height chosen to be 1.34" to enable using standard off-the-shelf optical mounts
- Base is the largest piece of bronze that will fit in the footprint on the lower optical table
- Where possible, ½" optics were used to save space



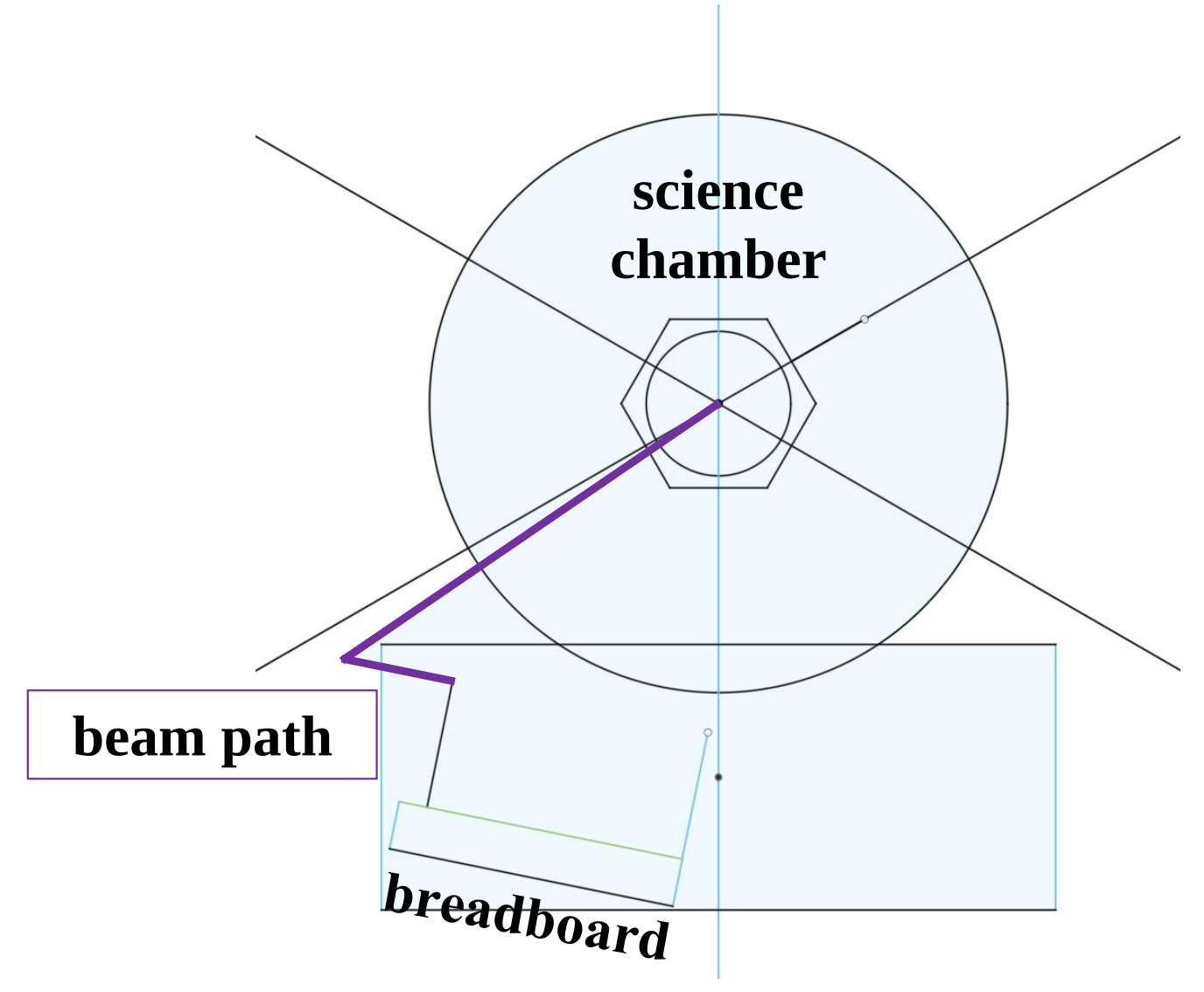
Final Lens Selection



- Lattice potential needs to stay overlapped with the atomic cloud/horizontal lattice potential as spacing is tuned
- Regular (singlet) lenses have spherical aberration, creating slightly different focal lengths at different positions on the lens [4]
- Decided to order custom f = 150 mm aspheric lens to avoid this

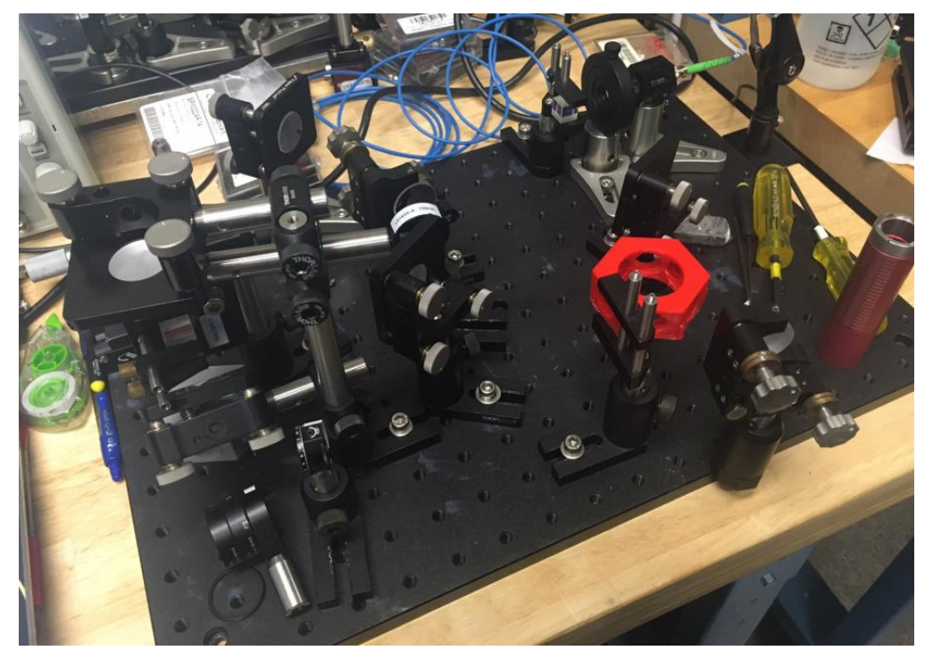
Fitting Everything Together

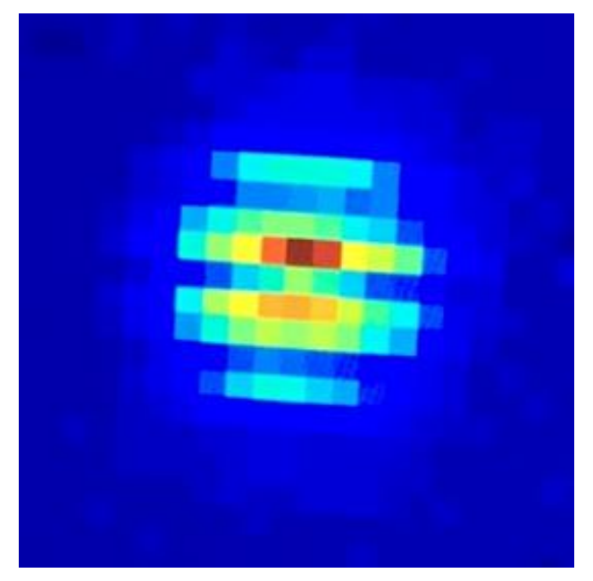
- Optics will be set up and aligned on a side bench
- After leaving the breadboard, the accordion lattice beams will be sent into the chamber via a final mirror on the horizontal lattice breadboard
- The beams will enter the chamber at a small angle from the lattice beam B1 output



Current Progress and Future Work

- Test lattice worked as expected
- Breadboard machining currently in progress
- Accordion lattice will be implemented on new potassium-40 experiment currently being set up





References and Acknowledgments

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[1] Gyu-Boong Jo, Jennie Guzman, Claire K. Thomas, Pavan Hosur, Ashvin Vishwanath, and Dan M. Stamper-Kurn. Ultracold atoms in a tunable optical kagome lattice. Phys. Rev. Lett., 108:045305, Jan 2012.
[2] E9: Optical kagome lattice, 2022.
[3] J. L. Ville, T. Bienaime, R. Saint-Jalm, L. Corman, M. Aidelsburger, L. Chomaz, K. Kleinlein, D. Perconte, S. Nascimbene, J. Dalibard, and J. Beugnon. Loading and compression of a single two-dimensional bose gas in an optical accordion. Phys. Rev. A, 95:013632, Jan 2017.
[4] Mansoor Sheik-Bahae. Lens aberrations and ray tracing, January 2018.

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