Progress toward a strontium magneto-optical trap (MOT)

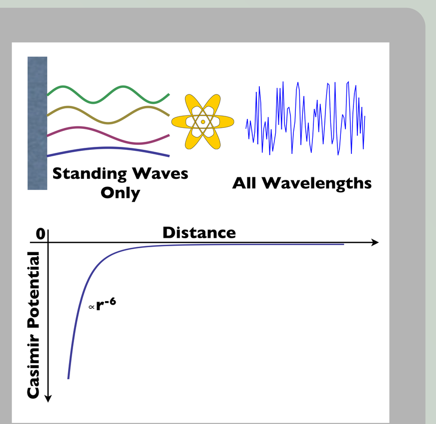
Tobias L. Brown-Heft, Eryn C. Cook, Paul J. Martin, Daniel A. Steck

Oregon Center for Optics, University of Oregon

Cold atoms as force sensors

Casimir-Polder potential

Casimir-type forces arise from vacuum fluctuations in the background electromagnetic field. Neutral bodies in vacuum impose boundary conditions which limit allowed field modes creating an imbalance in the vacuum radiation pressure. This results in potential energy shifts and mechanical forces which become important on small scales.

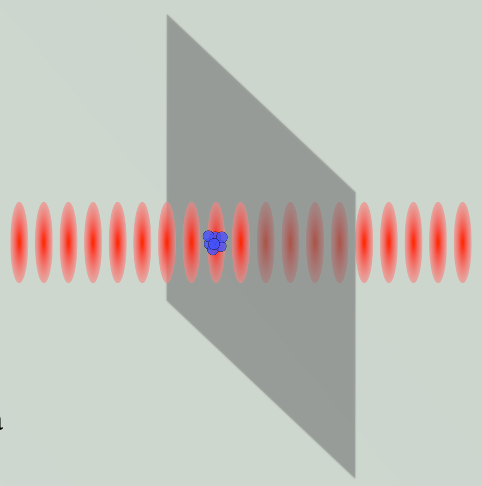


The Casimir-Polder interaction is the Casimir force between atoms and macroscopic bodies. As an atom is brought close to a surface, it experiences an attractive potential. These effects can be detected by probing narrow-linewidth "clock" transitions of atoms near surfaces.

These effects are important to understand for nanoscale technologies and miniaturization of atomic devices.

Proposal:

We will load cold, magneto-optically trapped atoms into an optical lattice. Energy shifts in a "clock" transition will be observed as the lattice is translated toward a dielectric surface.

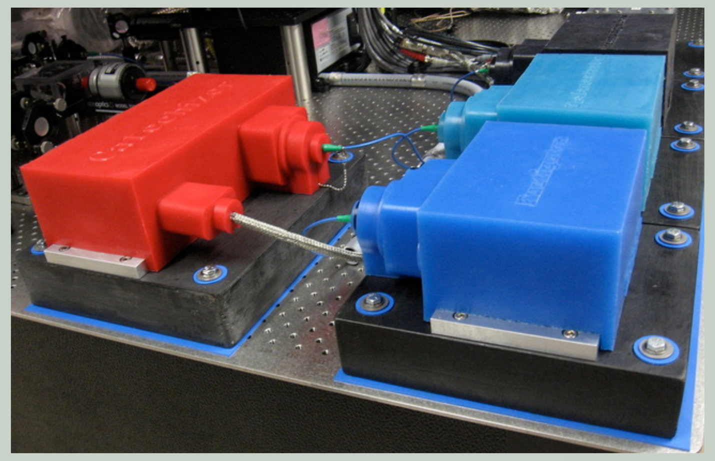


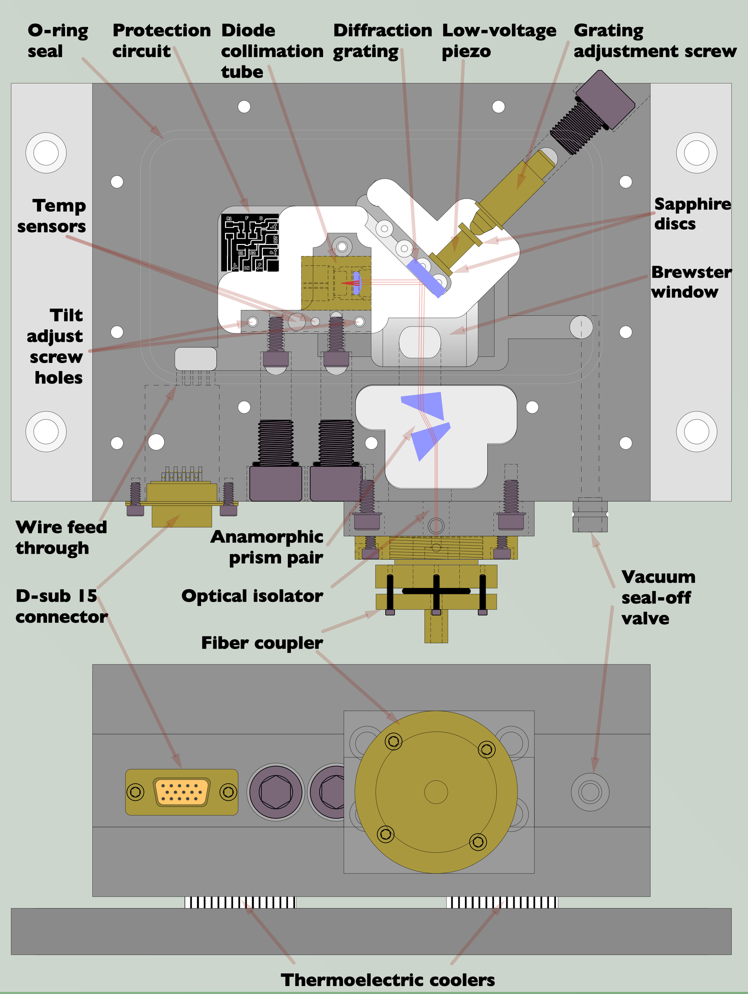
Strontium offers a narrow 7.6kHz linewidth transition at 689nm, and is amenable to both magneto-optical and dipole trapping. We have developed an in-house ultrastable diode laser; completion of the required laser systems and a vacuum system design are in progress.

Novel homemade extended cavity diode laser (ECDL)

Overview

- We developed[1] an alternative to commercial external cavity diode laser (ECDL) systems which offers simple assembly, lower cost, and superior performance.
- Design effectively isolates environmental noise for improved passive stability.
- Easily adapted to many different wavelengths.



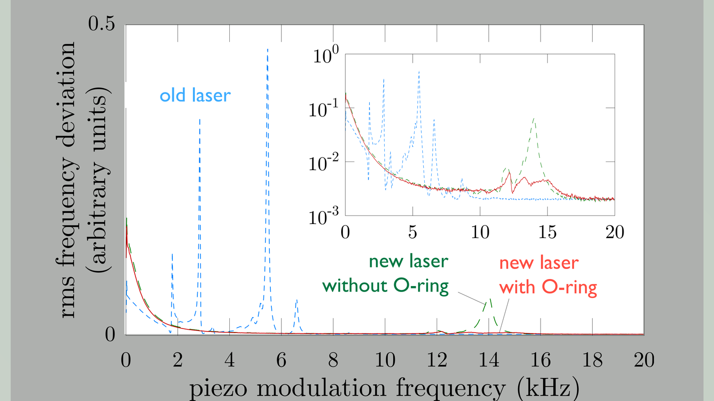


Features

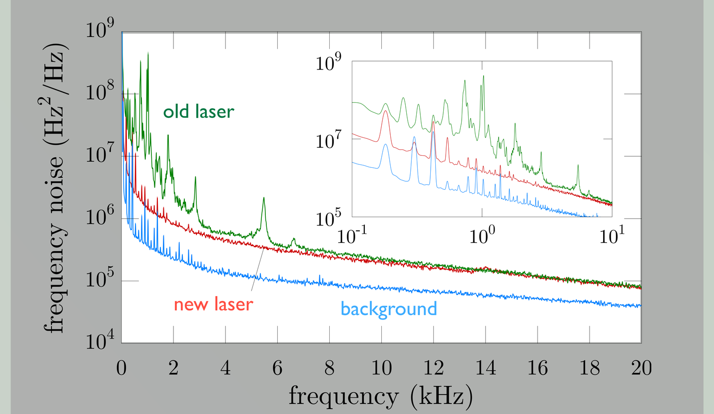
- "Unibody" design: main cavity made on CNC machine from a single aluminum block to minimize coupling of environmental noise to laser frequency
- Stiff and light grating arm for a high resonance frequency; shear damping minimizes lower resonances
- Hermetic- and vacuum- sealed cavity, encased in a molded silicon cover for further isolation from environmental perturbations
- Off-the-shelf peripherals, integrated beam shaping, and fiber-coupled output
- Cavity length easily extended for extra-narrow-linewidth models: we measured a 11.7 kHz free-running linewidth (observation time: .1ms) for our 689nm "clock" laser with a 10cm cavity length.
- Total cost of materials, parts, electronics, and machining is less than $5000
- Passive linewidths measured to be better than $30,000 commercial systems

Passive stability

Since environmental noise is dominated by low frequencies, eliminating resonances in this regime greatly improves performance



Above: response of laser as the grating arm is driven at acoustic frequencies (inset are the same data on a semilog scale). Resonances below 12 kHz are absent in the new laser.



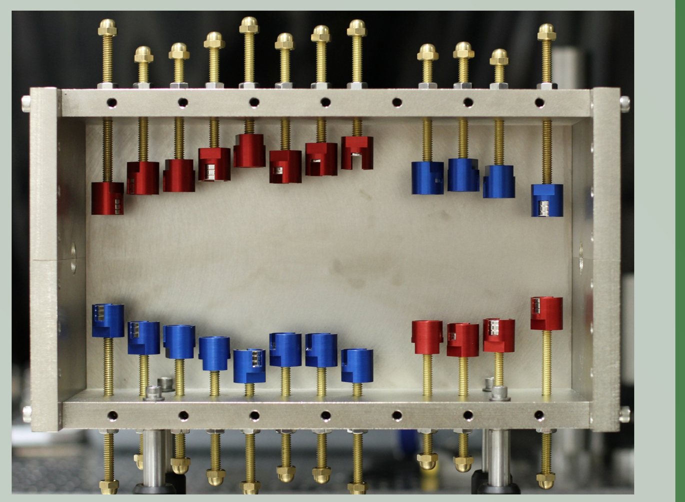
Above: passive noise measurements show how arm resonances dominate the noise spectrum of a free-running laser. The integrated noise of our new laser is much improved even in this "quiet" setting. In addition, we've observed that the laser's performance is still reasonable in a harsh environment.

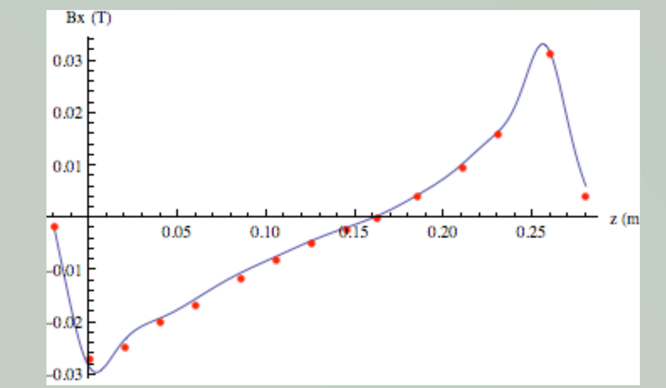
Zeeman Slower

Purpose

Hot Strontium atoms must be slowed to reasonable temperatures ~2K after leaving the nozzle in order to be effectively trapped by the MOT. Spontaneous absorption/emission cycling accomplishes this, but Doppler shifting causes the atomic transition to fall off resonance with the laser source.

This Zeeman Slower[2] uses the energy shift due to an external magnetic field to cancel out the Doppler shift in order to allow effective cooling of a fast atomic beam. Strontium's energy structure allows the utilization of a transverse magnetic field and a zero point, which opens the possibility for the use of powerful rare earth magnets to generate our magnetic field profile.





Above: Zeeman Slower transverse magnetic field component versus longitudinal direction. Blue Line: Calculated Profile; Red Dots: Measured Values

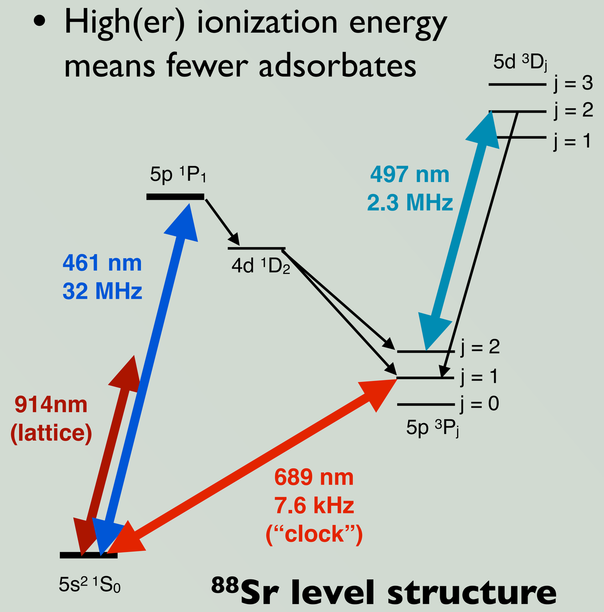
Features

- Permanent magnets require no electrical power or water cooling.
- Magnetic field profile is easily tunable
- Housing machined from high magnetic permeability cast iron to shield the rest of the vacuum system from powerful magnetic fields.
- Small housing form factor allows a more compact vacuum system design.
- Only requires twice as much laser intensity as traditional wire-wound slowers.

Strontium: advantages and challenges

Benefits

- Narrow "clock" transition gives increased energy resolution
- Convenient "magic wavelength" can be used to eliminate light shift from our optical lattice
- Zero nuclear spin
- High(er) ionization energy means fewer adsorbates

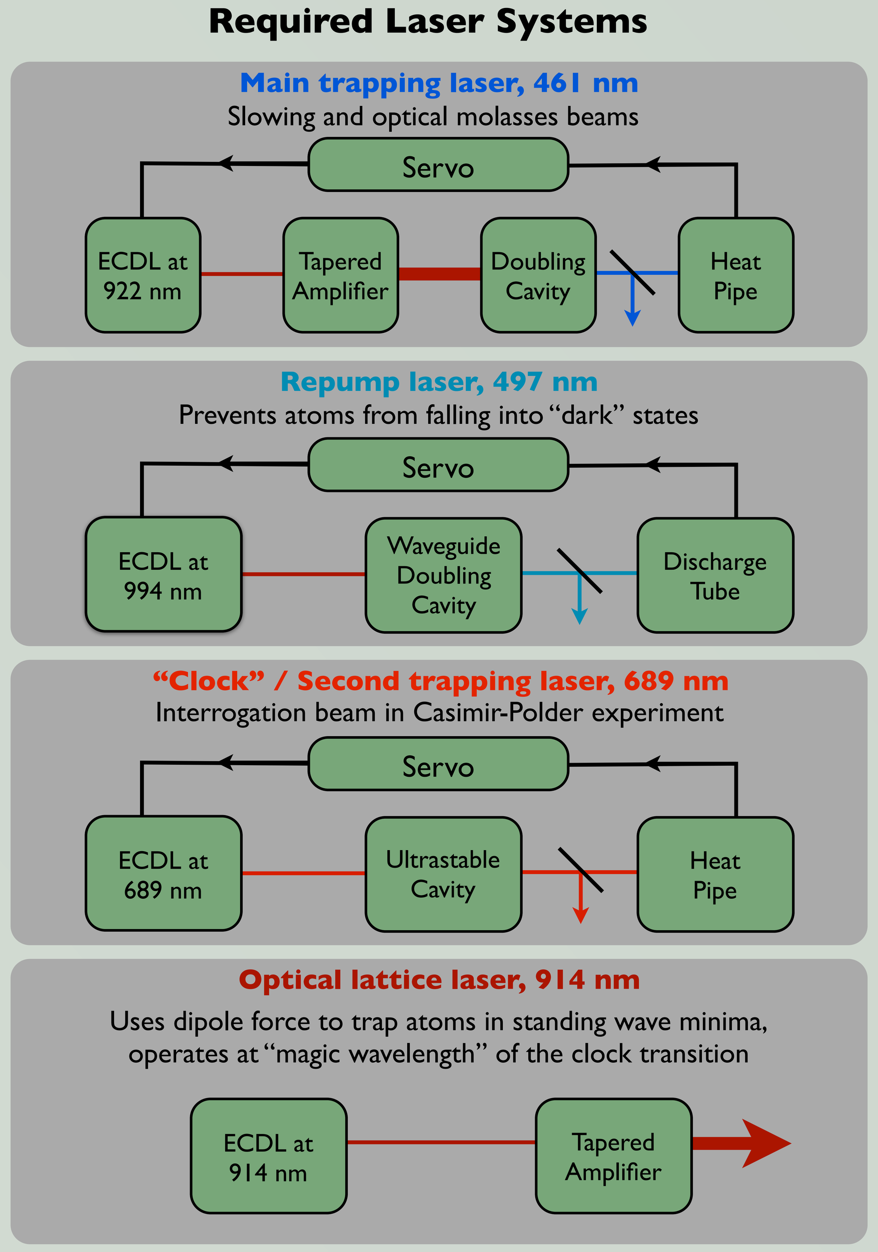


⁸⁸Sr level structure

Experimental issues

- Group II elements have two valence electrons and more complicated structure
- Four laser systems at very different wavelengths are required
- An ultrastable, narrow-linewidth laser (linewidth < 1 kHz) will be needed to interrogate shifts in the "clock" transition

Required Laser Systems



- Strontium's low vapor pressure means we must heat it to several hundred degrees Celsius to obtain a gas
- Strontium is highly reactive, and should be isolated from windows, copper gaskets, and other elements prone to corrosion

Vacuum system

Requirements

- Ultra-high vacuum for MOT regions.
- High temperature oven for adequate Sr vapor pressure
- Collimated atomic beam for low loss and effective slowing
- Valve off oven side of vacuum system for Sr replacement w/o high vacuum side re-bake

Strontium oven

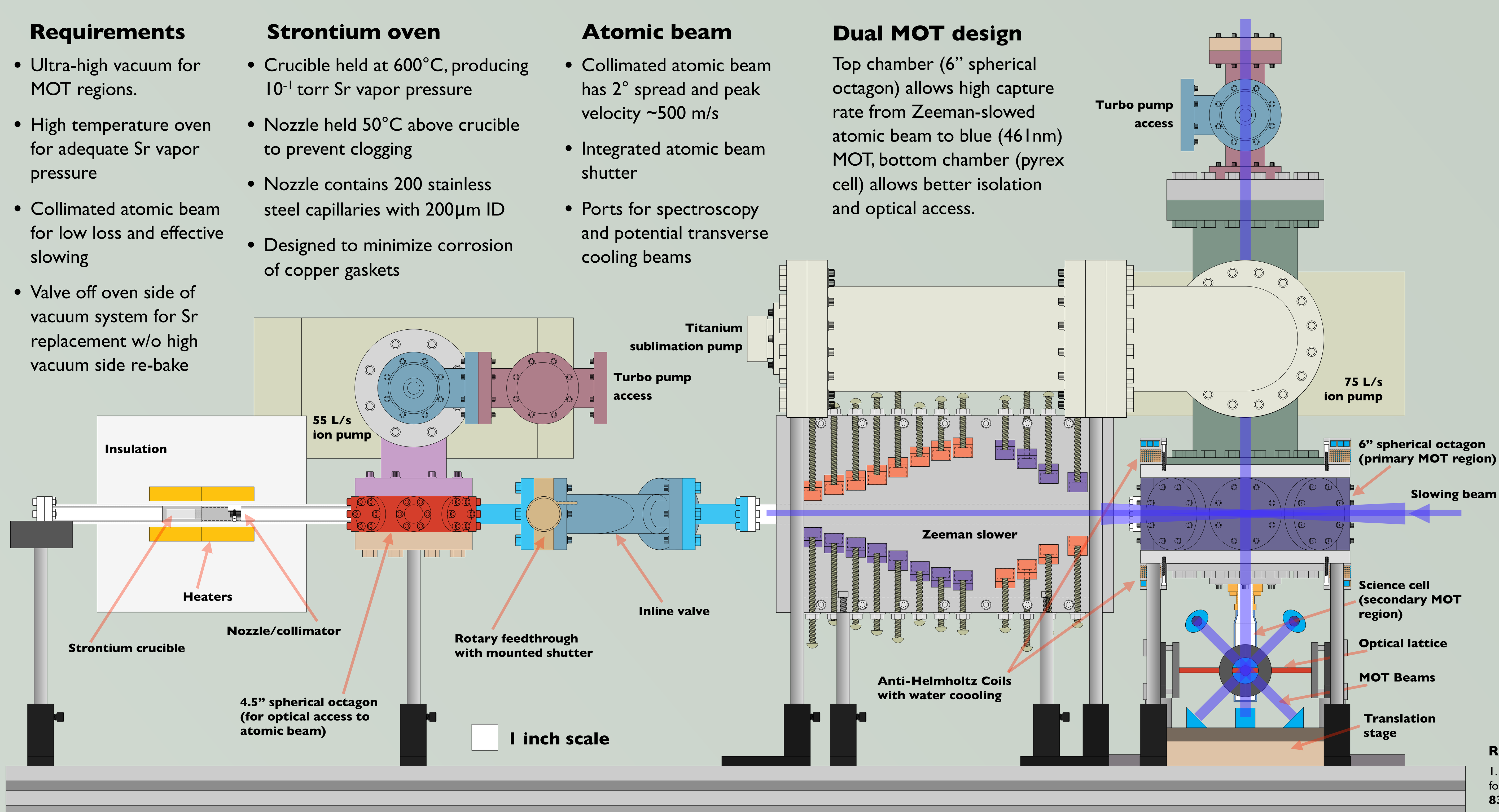
- Crucible held at 600°C, producing 10^{-1} torr Sr vapor pressure
- Nozzle held 50°C above crucible to prevent clogging
- Nozzle contains 200 stainless steel capillaries with 200μm ID
- Designed to minimize corrosion of copper gaskets

Atomic beam

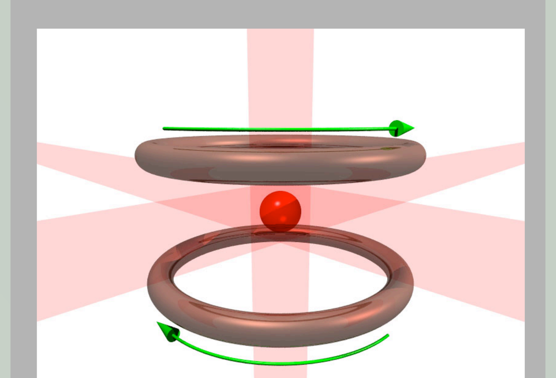
- Collimated atomic beam has 2° spread and peak velocity ~500 m/s
- Integrated atomic beam shutter
- Ports for spectroscopy and potential transverse cooling beams

Dual MOT design

Top chamber (6" spherical octagon) allows high capture rate from Zeeman-slowed atomic beam to blue (461nm) MOT, bottom chamber (pyrex cell) allows better isolation and optical access.



Magneto-Optical Trapping



http://www.pit.physik.uni-tuebingen.de/zimmermann/forschung/mixt/mixt_mot.jpg

- Anti-Helmholtz Coils generate a magnetic quadrupole with zero point at center of trap
- Position-varying magnetic field causes atomic transition to shift for off-center atoms
- Red-detuned light pushes shifted atoms back to the center by spontaneous absorption/emission cycling

References

1. E. Cook, et al, "High passive-stability diode-laser design for use in atomic-physics experiments," *Rev. of Sci. Instrum.* **83** , 043101(2012).

2. Y. Ovchinnikov, "A permanent Zeeman slower for Sr atomic clock," *The European Physical Journal* **183**, 1 (2008).