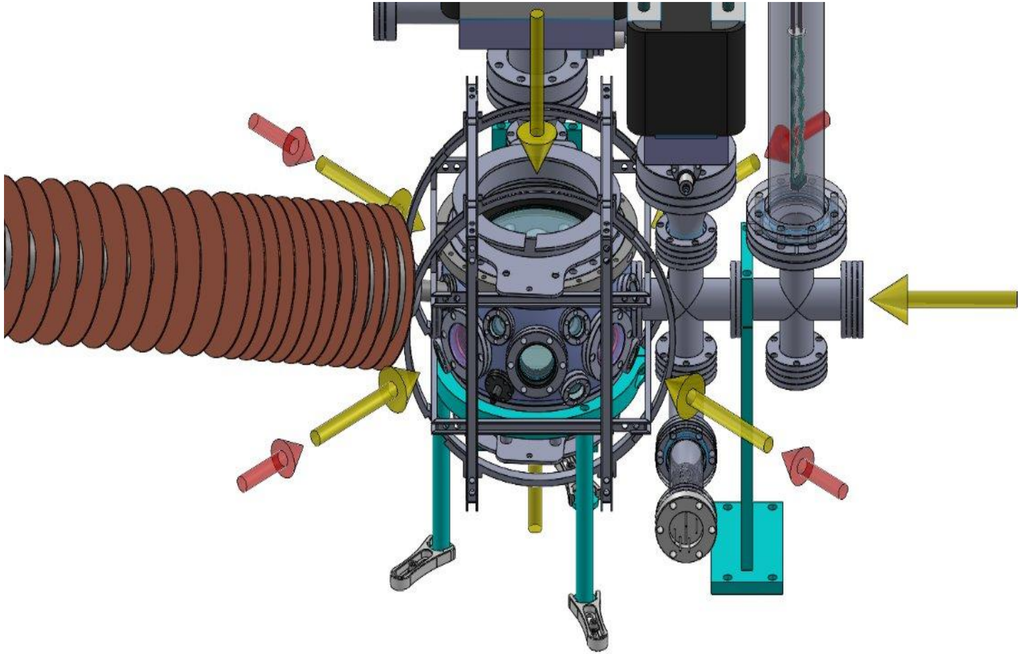
Laser Cooling & Optical Dipole Trap



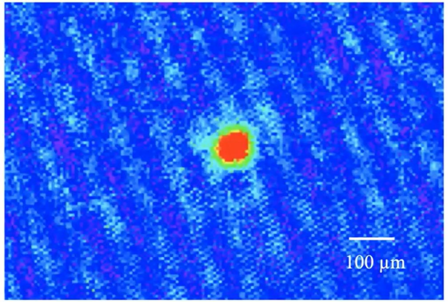
Student: Carlos Alvarado

Advisor: Dr. Arne Schwettmann

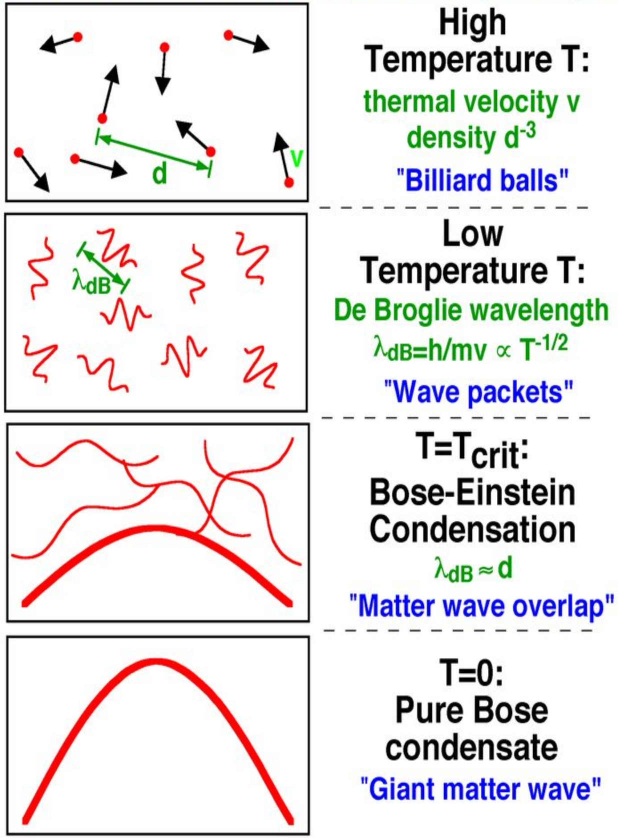
REU 2024

Bose-Einstein Condensate

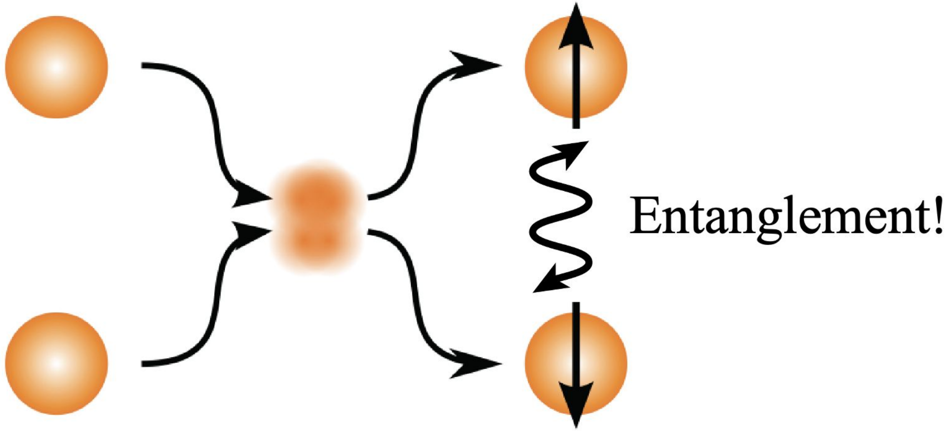
- Ultra-cold gas
- Composed of Bosons
- De Broglie wavelength: $\lambda = h/p$
- Wave Functions overlap
- Indistinguishable
- Macroscopic population of the ground-state of the trap potential

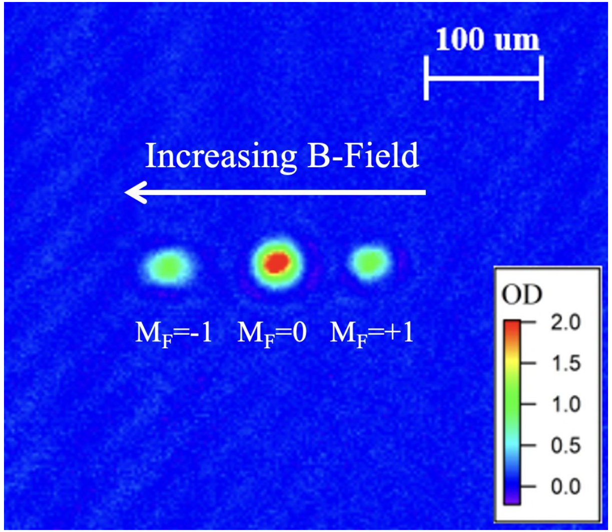


~20,000 atoms in our pure BEC after 10 ms expansion (false color absorption image)



Motivation

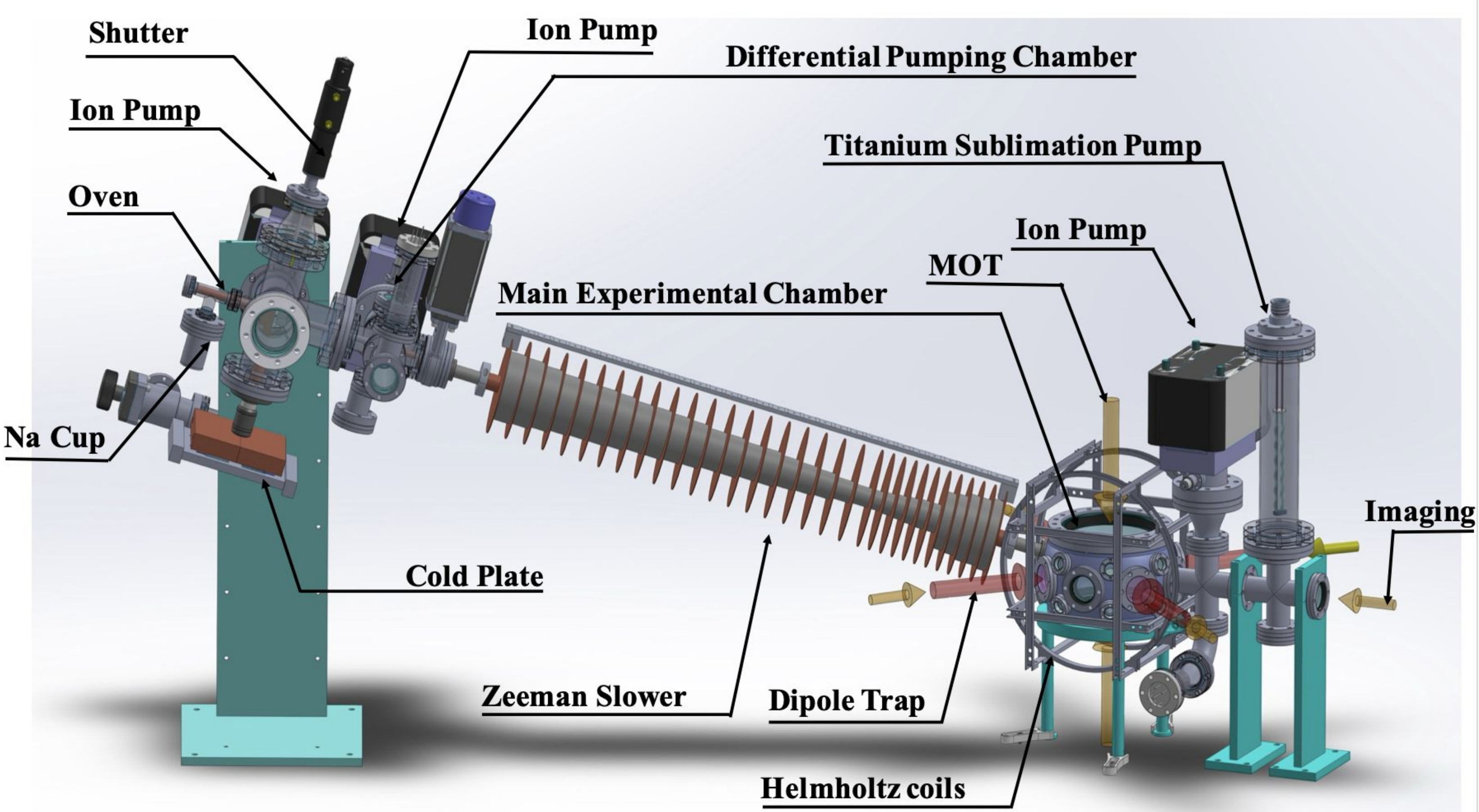




F=1 Spinor BECs:

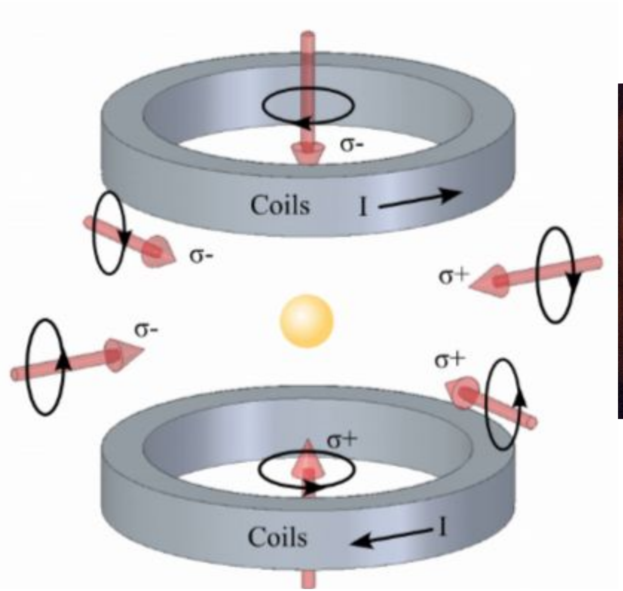
- Spin texture and spin waves in elongated BEC (Bigelow, Univ. of Rochester and Sengstock, Hamburk Univ.)
- Collisions in BEC happen coherently and are controllable
    - Matter-wave quantum optics in spin space
    - Atom interferometer with quantum-enhanced sensitivity
    - Prototyping for quantum technologies such as quantum-enhanced sensors and phase-sensitive amplifiers

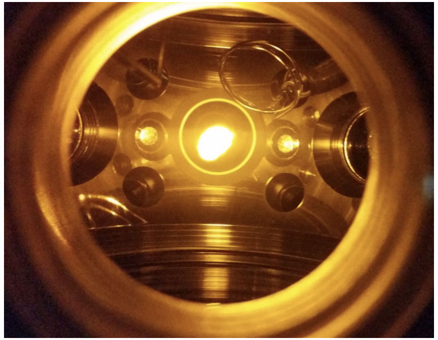
Spinor BEC Setup



Magneto-Optical Trap

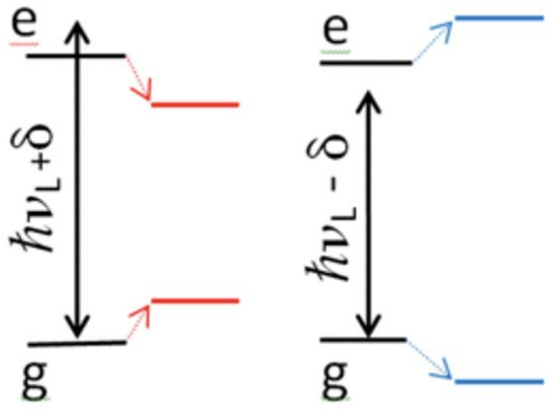
- Laser cooling reduces temperature @ 589 nm
- Magnetic fields compresses the cloud to the center
- N ~ 1 billion
- T ~ 80 μK
- n ~ $8 \cdot 10^9$ atoms/cm³
- Photon recoil causes heat via trembling motion, random walk

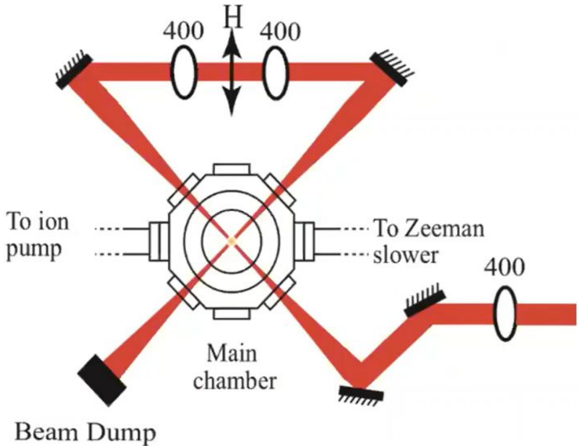




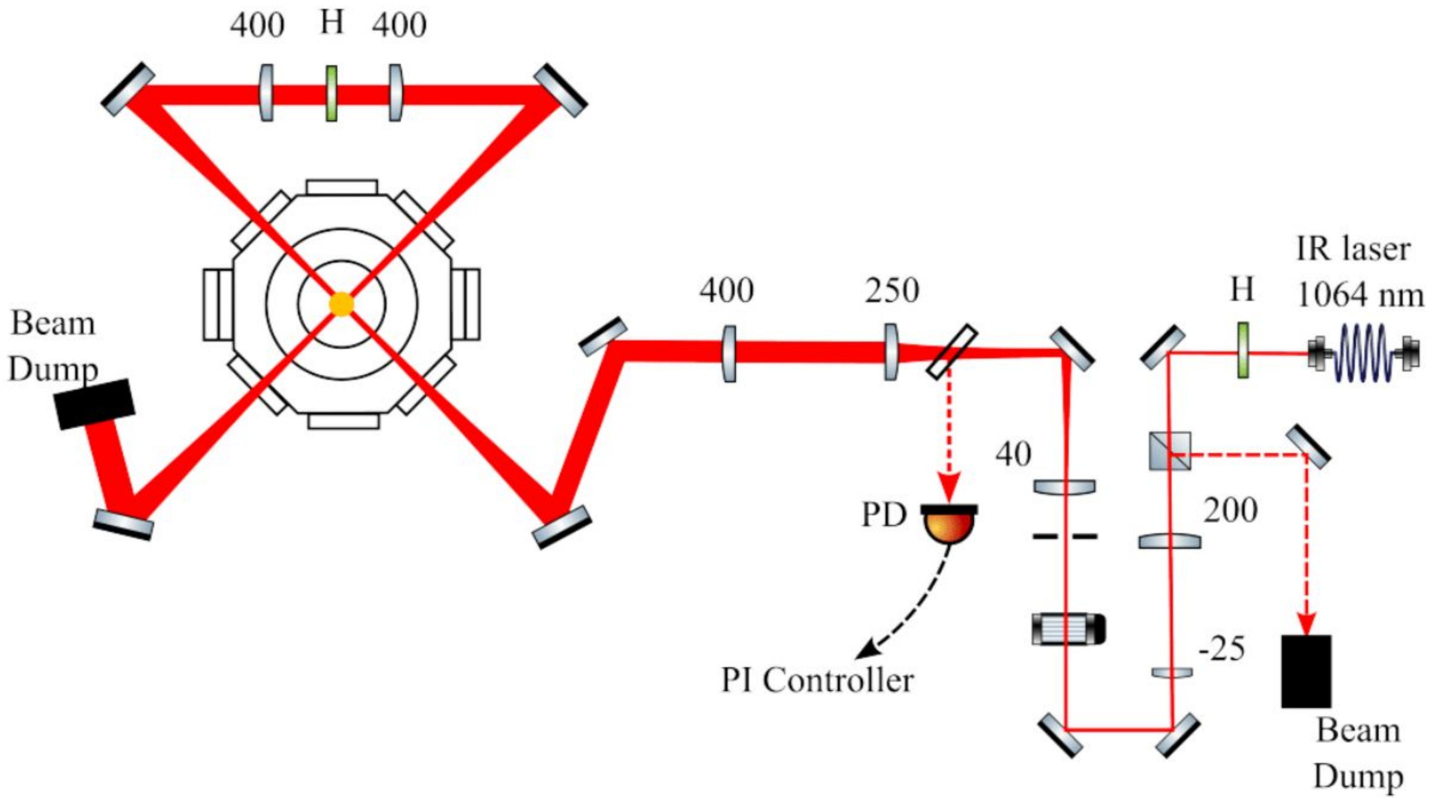
My Work: Optical Dipole Trap

- Far red-detuned beam @ 1064 nm
- No absorption of photons
- No recoil heating
- AC Stark effect → energy shift
- Crossed-focus of a high intensity beam at the center of the MOT
- Atoms are trapped at the center of the focus

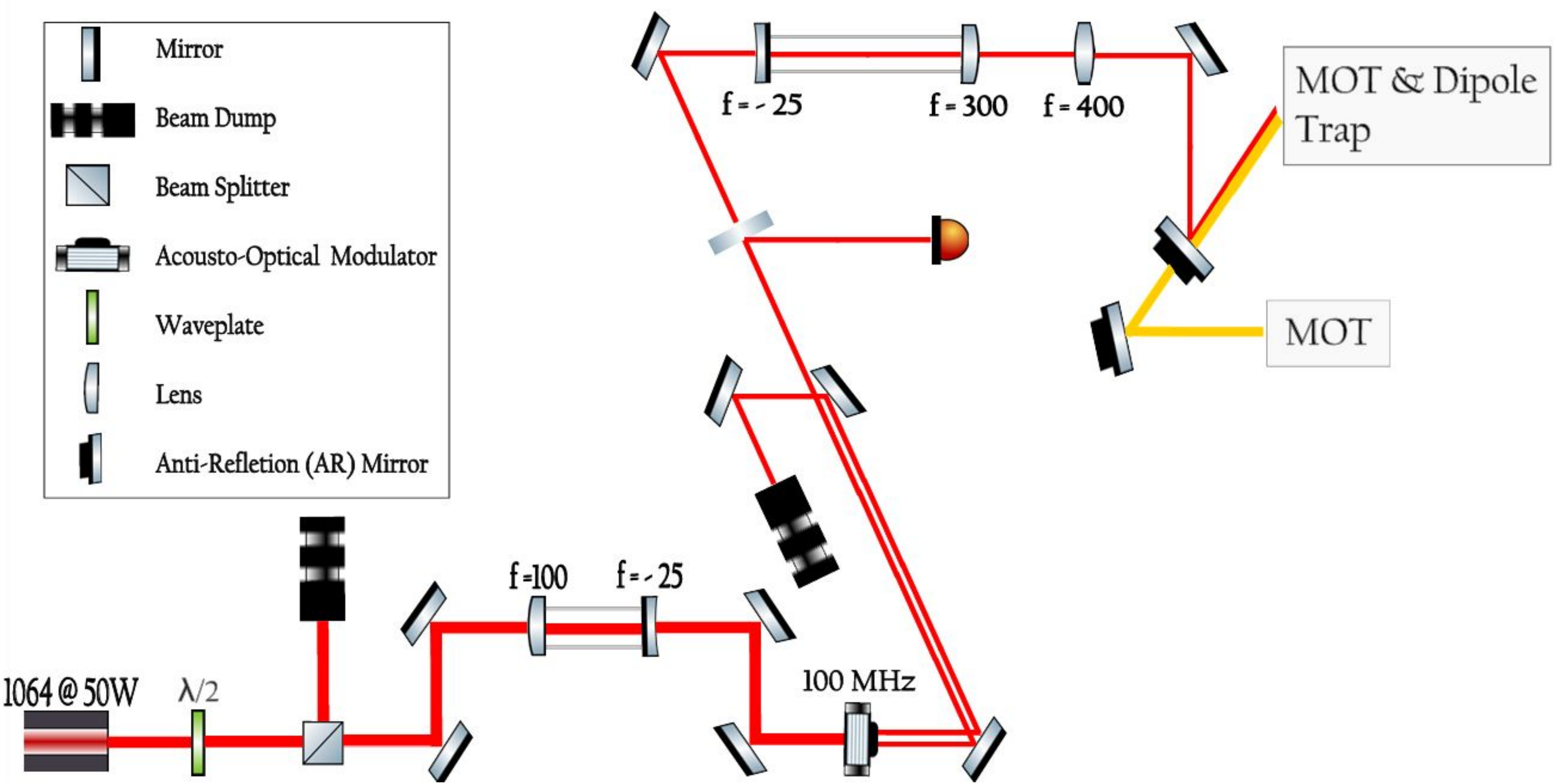




Old Dipole Setup

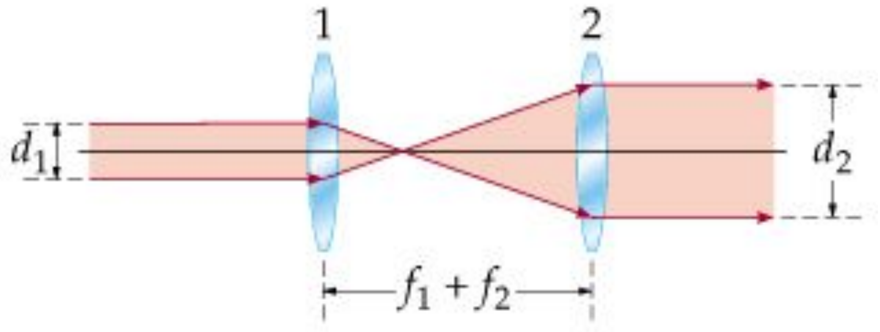


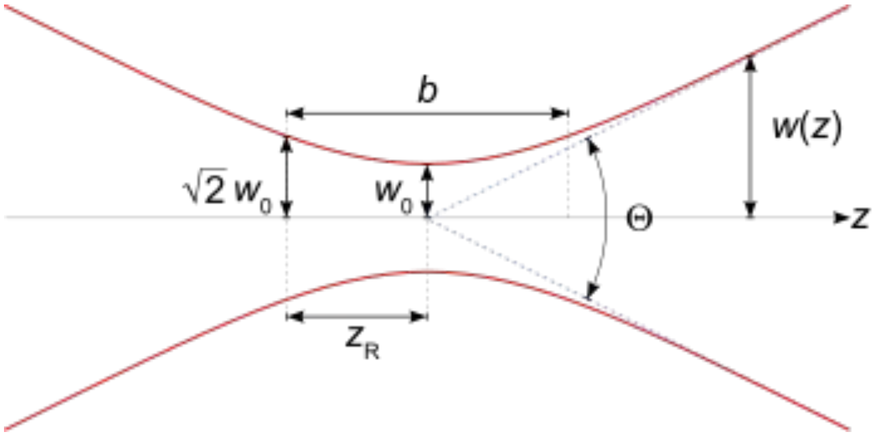
New Optical Dipole Trap Set-Up



Collimation & Rayleigh length

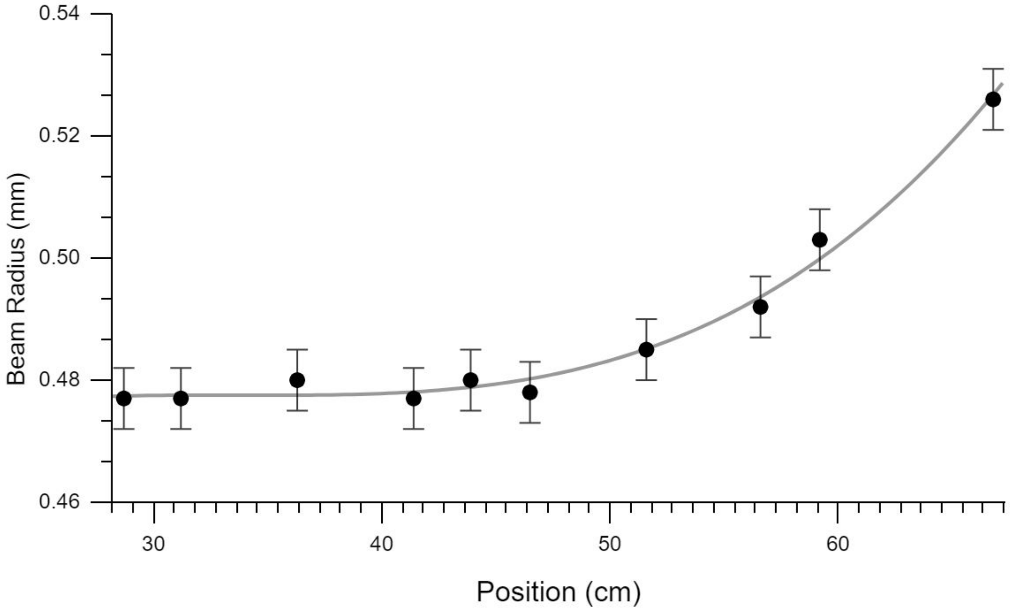
- Ray optics VS Gaussian beam optics
- Telescope alters the beam diameter
- Rayleigh Length:
  cross-sectional area increased by √2





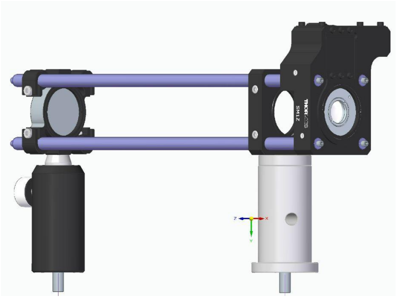
Telescope 1

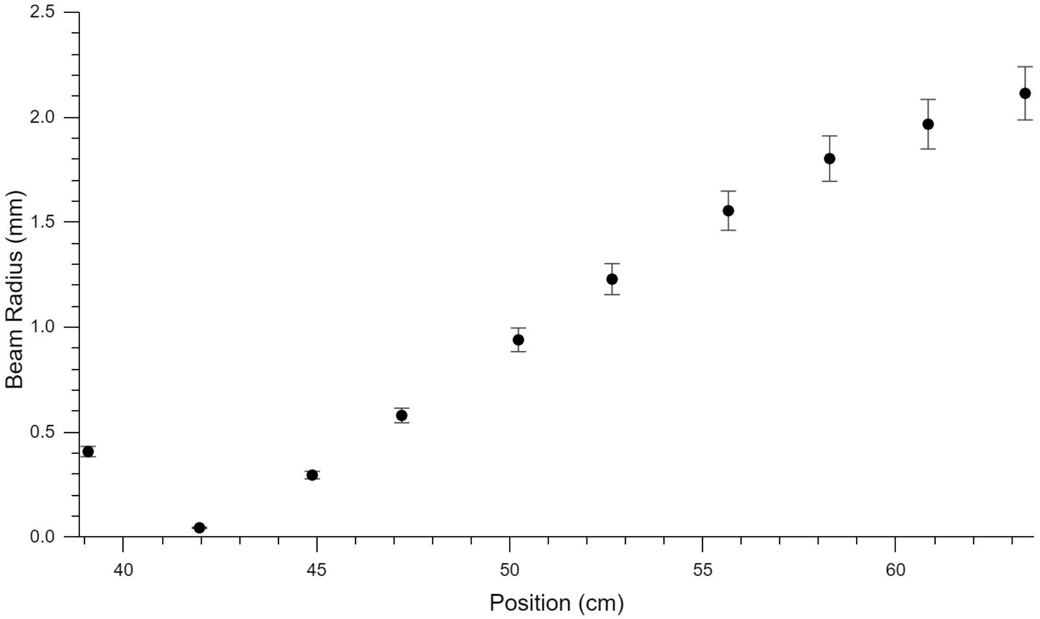
- Protect the AOM (Collimate beam)
- Change Diameter
  - Incoming: 3.5 mm
  - Outgoing: ~1.00 mm
- f_1 = -25 mm, f_2= 100 mm
- AOM: 13.97 cm
- Z_0 = ~ 8 cm



Telescope 2

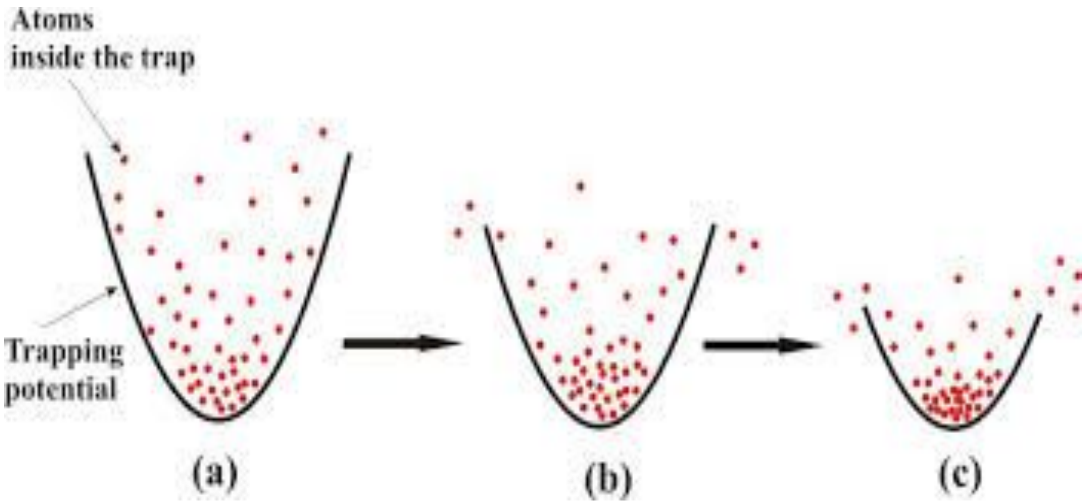
- Confine the particles
- Change Diameter
  - Incoming: ~1.0 mm
  - Outgoing: ~ 6.5 mm
- f_1 = -25 mm, f_2= 300 mm
- ω_0 = ~30 µm





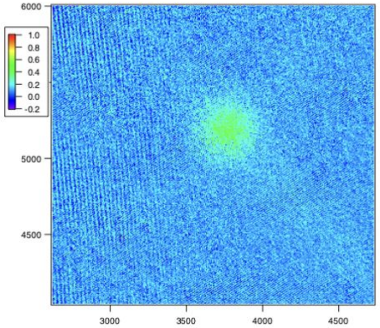
Evaporative Cooling

- Slowly reduce IR laser intensity
- Trap becomes more shallow
- High Energy Atoms leave the trap
- Remaining atoms rethermalize to cooler temperatures
- Nano-Kelvin Regime

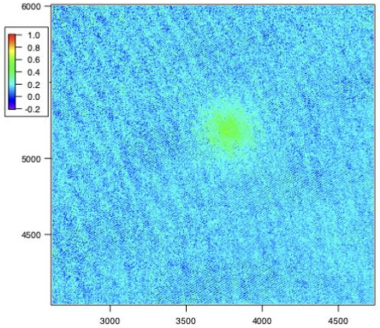


Evaporative Cooling In The Lab

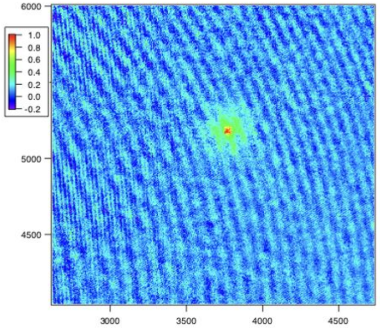
Time-of-flight absorption images of all-optical sodium Bose-Einstein condensate via evaporative cooling, ramping down dipole trap laser power from P = 40 W to P_f



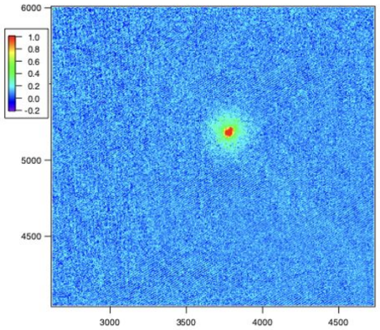
P_f = 281 mW



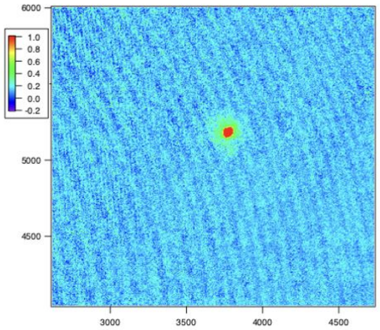
P_f = 234 mW



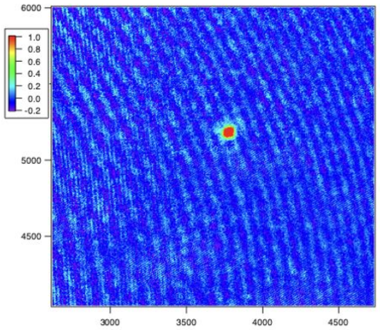
P_f = 198 mW, BEC appears!



P_f = 179 mW



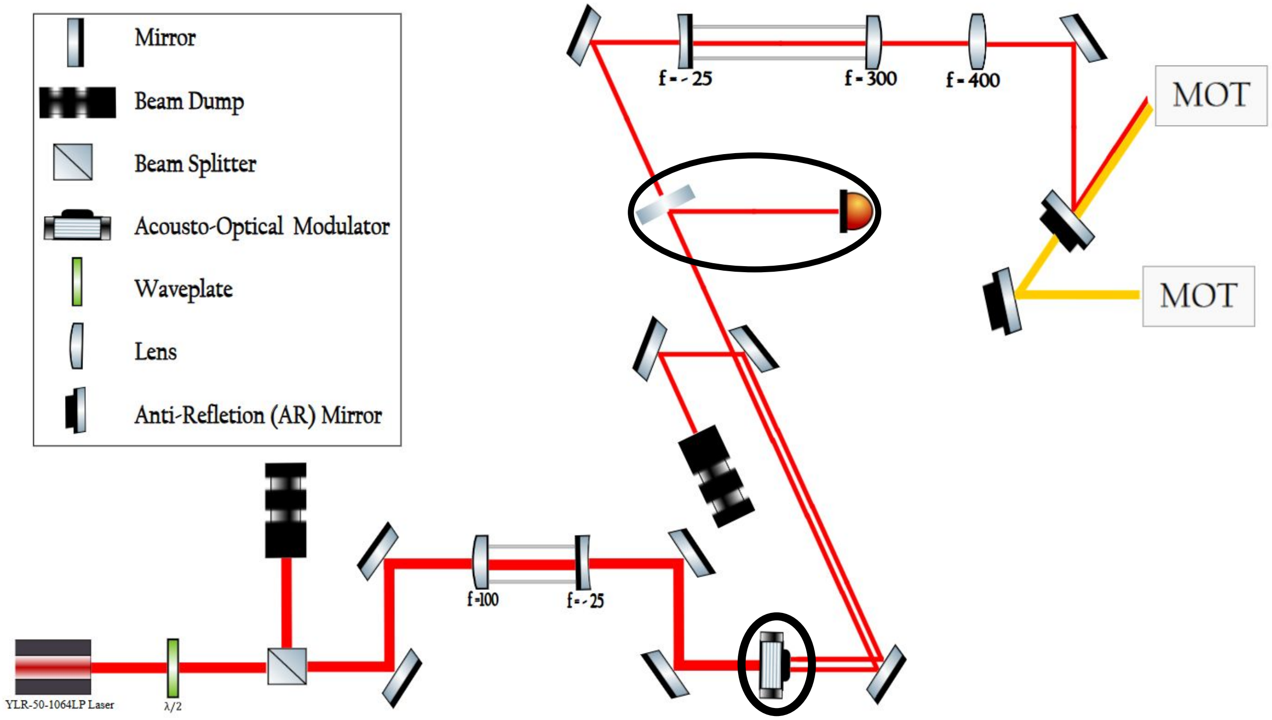
P_f = 143 mW



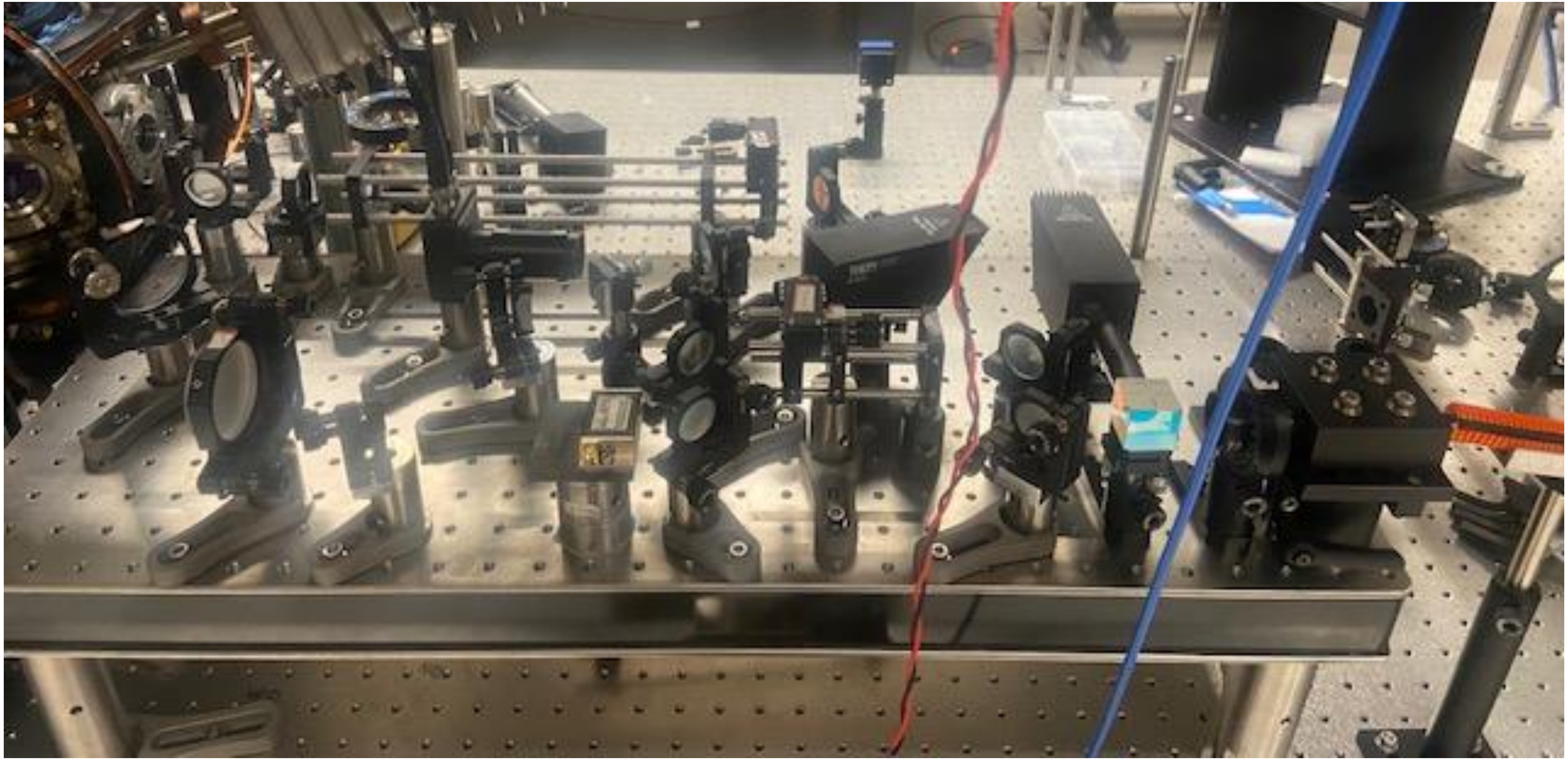
P_f = 125 mW, almost pure BEC!

AOM & Photodetector

- Photodetector: Measure the intensity
- AOM: control the intensity of the beam
- AOM: Change the the frequency



Dipole Trap In the Lab



Conclusion & Outlook

- Built the optical dipole trap system from scratch
- Optimized 3 telescopes
- Aligned and tested AOM
- Measured focus beam waist of ~30 μm
- Next Step: Trap atoms in dipole trap
- Will apply to OU! (Please take me 🙏 😭)


ANY
QUESTIONS